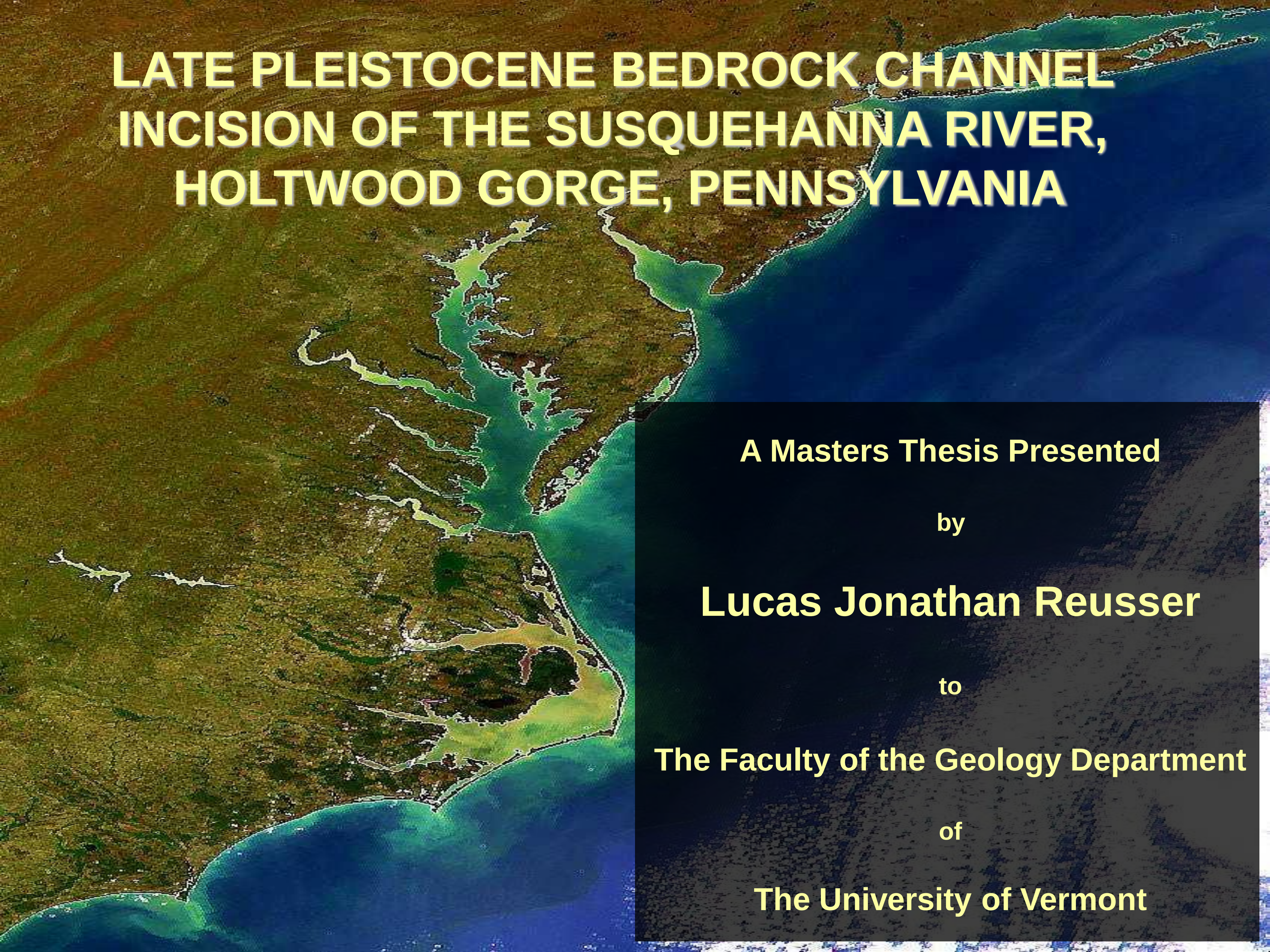


LATE PLEISTOCENE BEDROCK CHANNEL INCISION OF THE SUSQUEHANNA RIVER, HOLTWOOD GORGE, PENNSYLVANIA

A Masters Thesis Presented

by

Lucas Jonathan Reusser

to

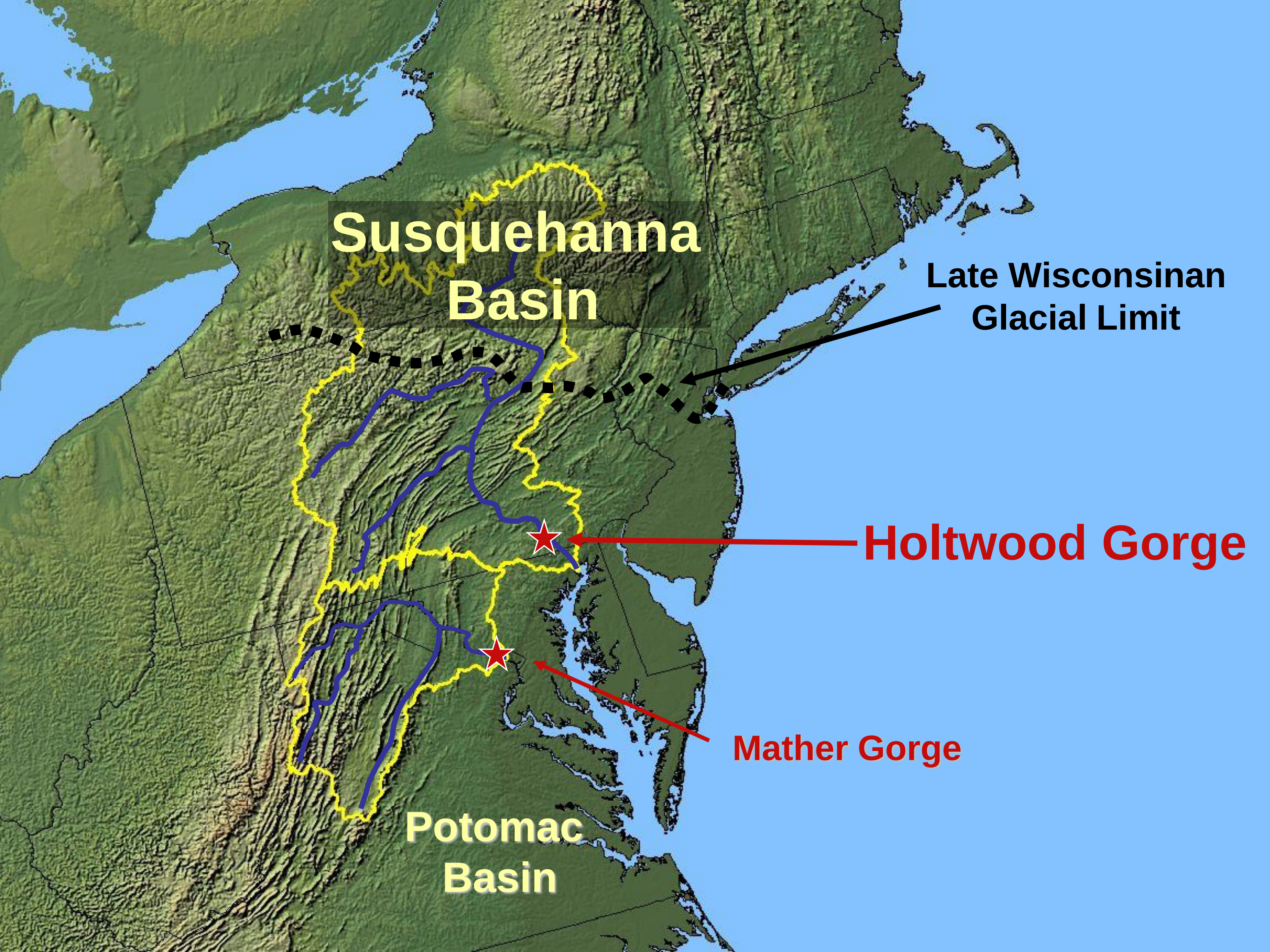
The Faculty of the Geology Department

of

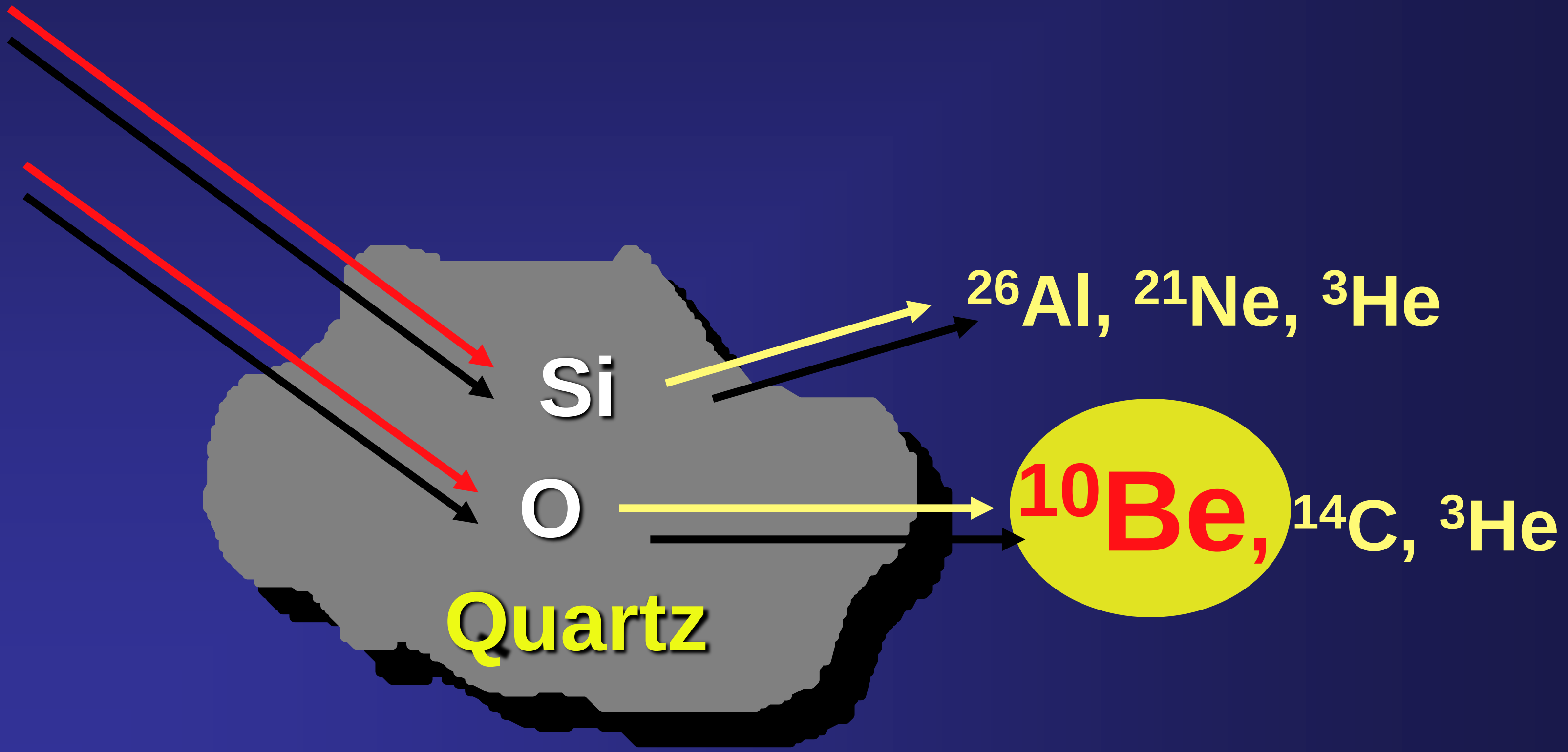
The University of Vermont

Presentation Outline

- Problem statement and background
- Dating river incision with ^{10}Be
- Holtwood Gorge field area
- Timing and style of bedrock channel incision
- Potential drivers of incision
- Conclusions
- Future avenues of research

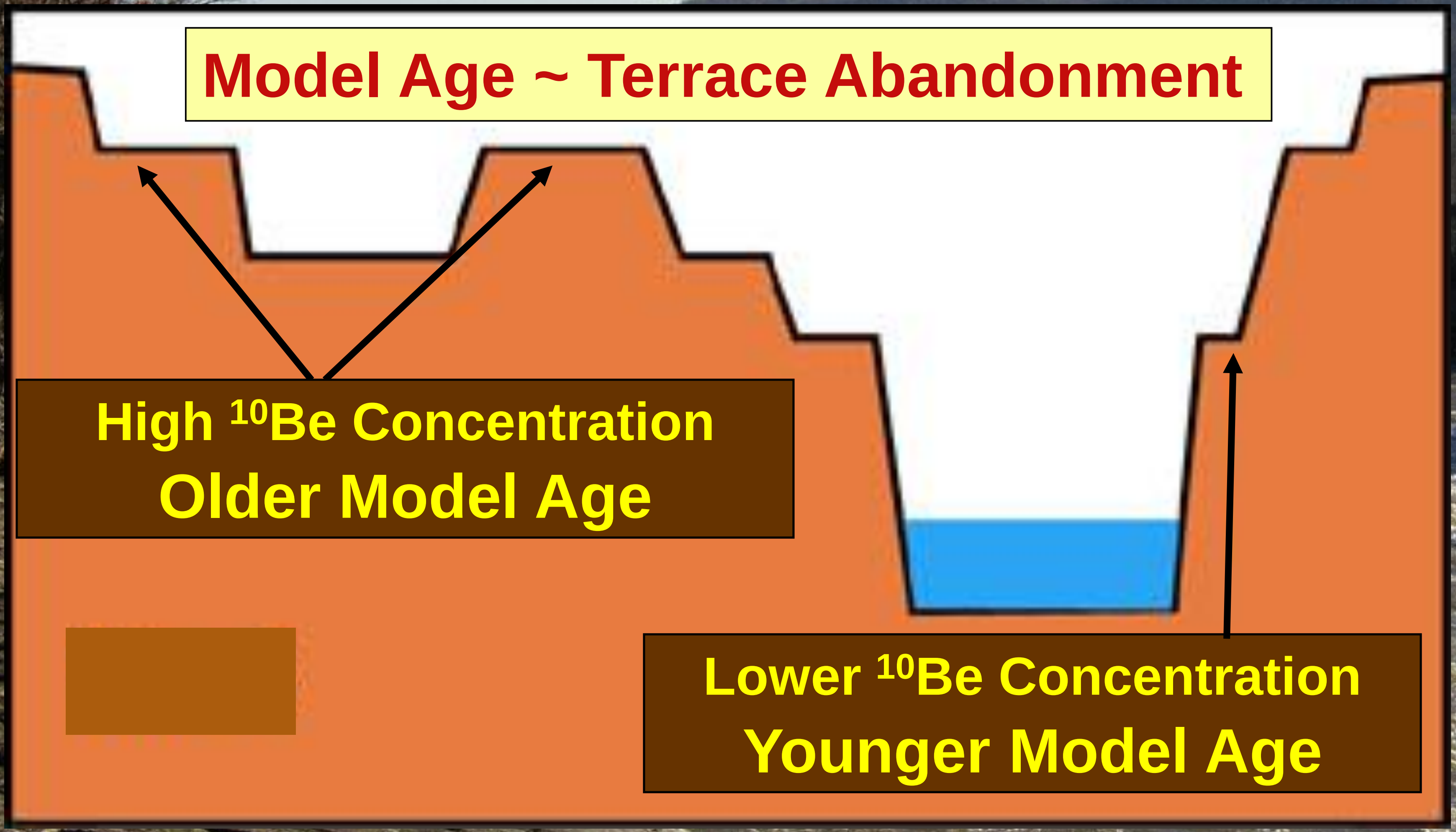

Susquehanna
Basin
Late Wisconsinan
Glacial Limit
Holtwood Gorge
Mather Gorge
Potomac
Basin

Cosmic ray bombardment *in situ*



5.2 atoms/g/yr

Dating Bedrock Terraces



Significance of Research

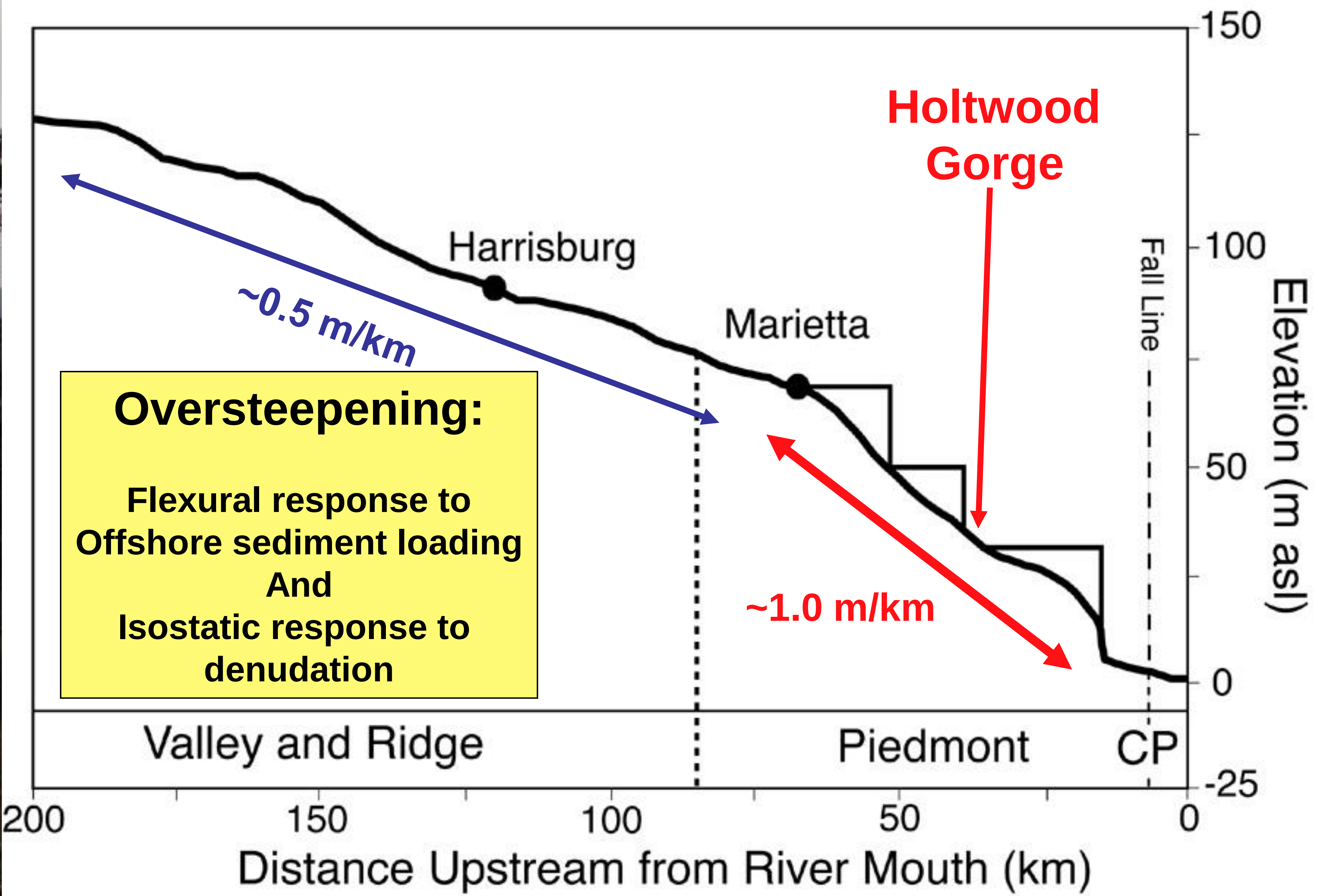
- River incision through bedrock has important implications for landscape development.
- Recent efforts to directly measure or model rates of incision with numerical simulations may not capture the timing and/or nature of dominant erosional processes.
- Very little is known about how, when, or why passive margin rivers incise through bedrock.
- Age control is mandatory to decipher how passive margin rivers respond to glaciation, climate, land-level, and/or sea-level.

Goals of The Project:

- Estimate the age of bare-rock strath terraces within Holtwood Gorge.
- Investigate the spatial patterning of erosion.
- Determine the timing and rate of incision within the gorge.
- Consider potential drivers of incision.
- Refine this new application of cosmogenic dating.

Field Work in Holtwood Gorge

Long-Profile of the Susquehanna



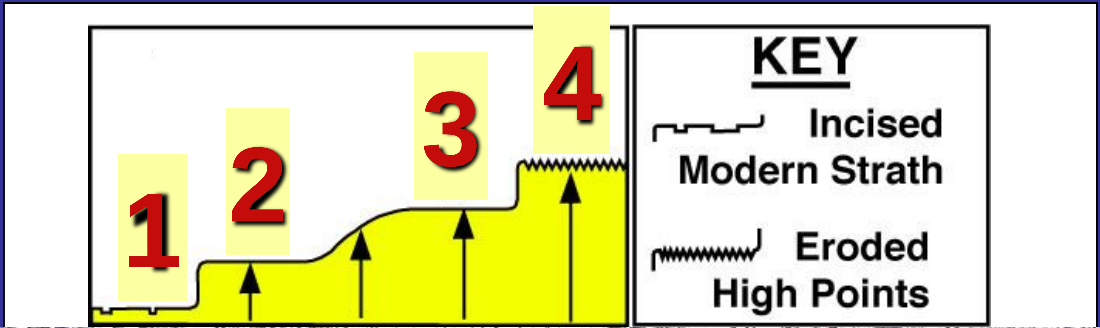
Oversteepening:

Flexural response to Offshore sediment loading And Isostatic response to denudation

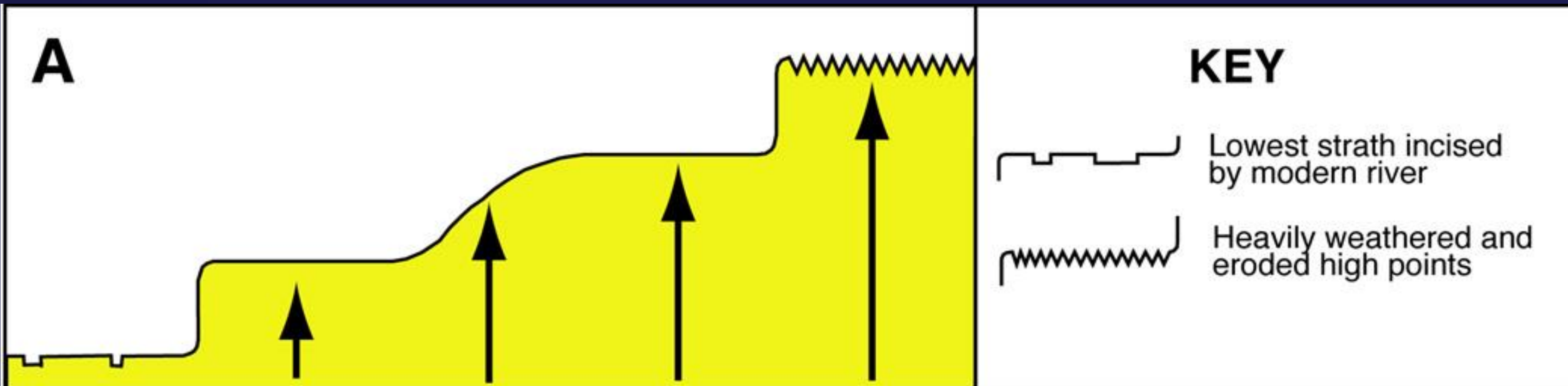
Holtwood Gorge Field Area

- Located approximately 50 km upstream from Chesapeake Bay and immediately below Holtwood Dam.
- Carved into the Wissahickon Schist of the Appalachian Piedmont.
- Harbors three distinct levels of bedrock terraces.
- Accessible by canoe.
- Abundant extractable quartz.

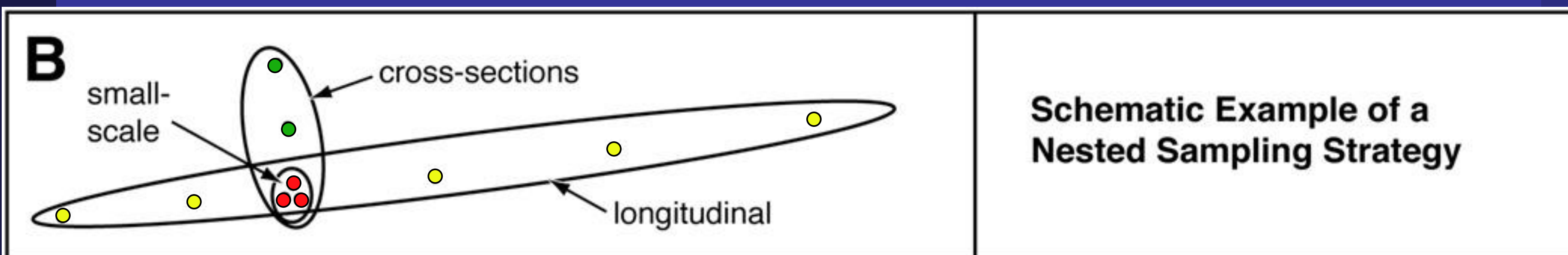
Bedrock Terrace Levels



Nested Sampling Strategy



1	2	Intermediate	3	4	Terrace Level
13	23	22	16	2	Total Number of Samples Collected



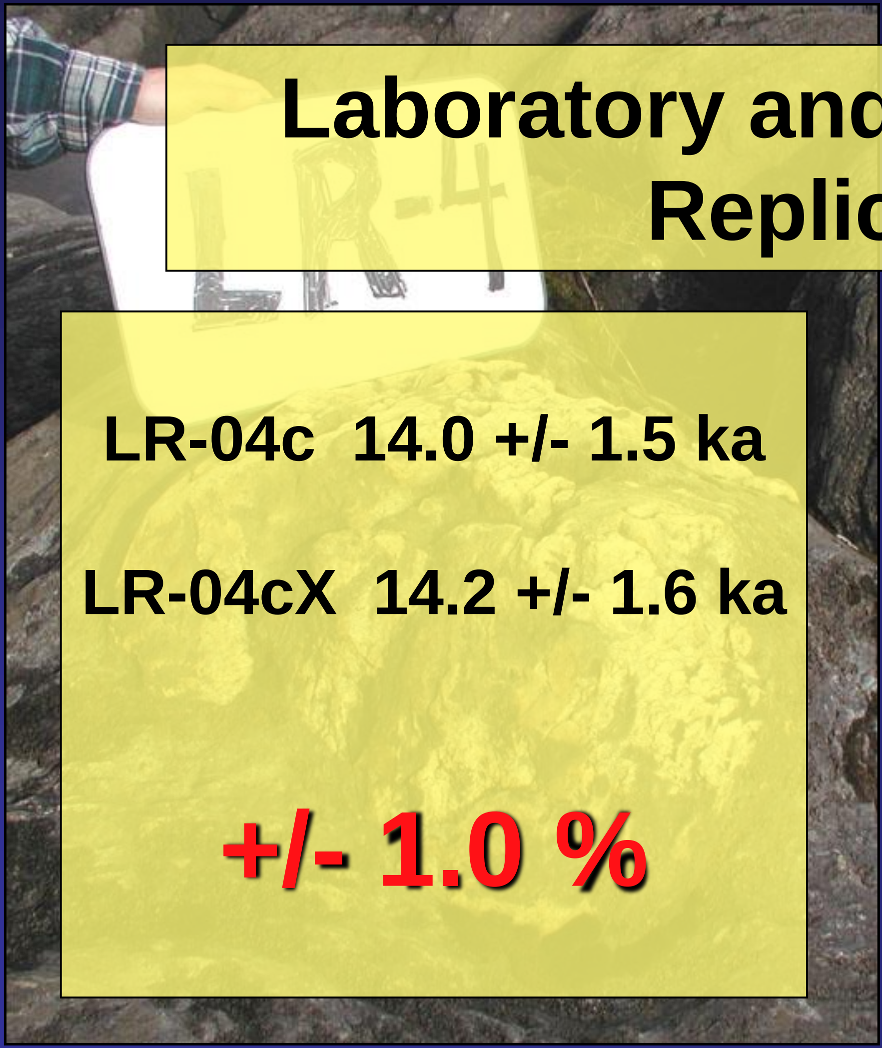
Lab Work and Nuclide Measurement

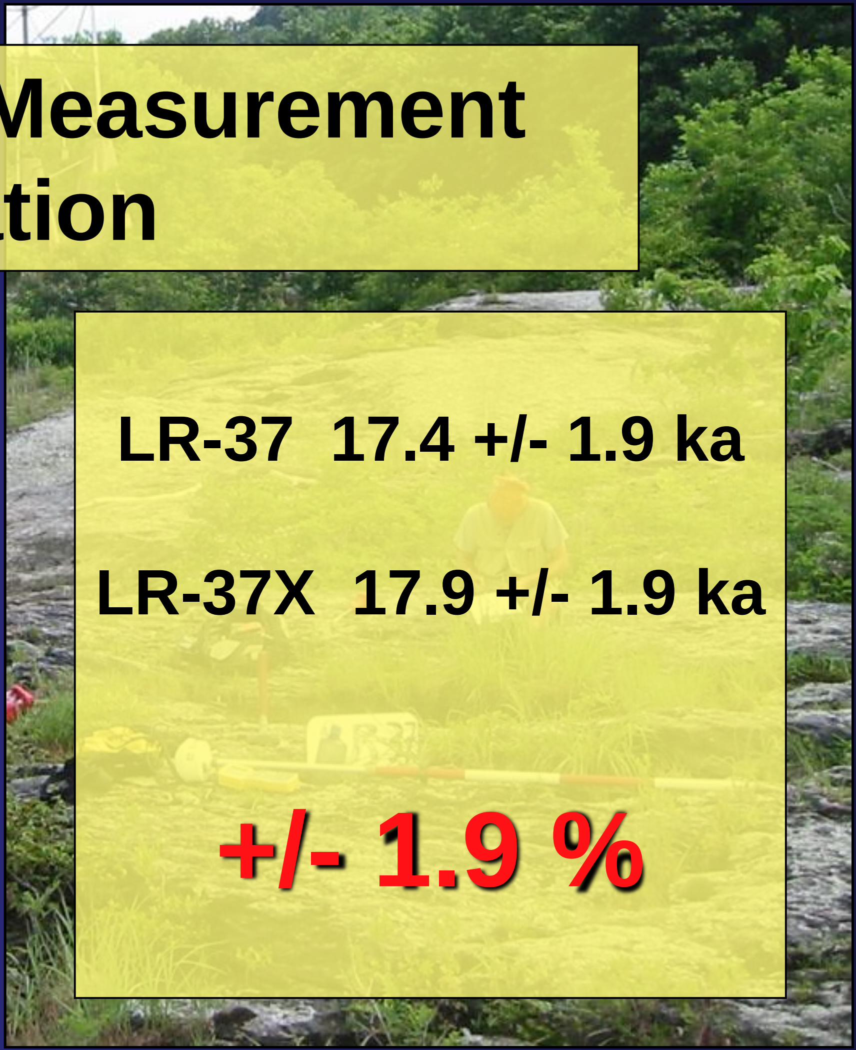
(From Piles of Rocks to Piles of Numbers)

- Quartz Purification
- Chemical Isolati
- Accelerator Mas Measurement at Livermore Natio

Spatial Patterning of Erosion in Holtwood Gorge

Does the Livermore Accelerator really work??





Laboratory and Measurement Replication

LR-04c 14.0 +/- 1.5 ka

LR-04cX 14.2 +/- 1.6 ka

+/- 1.0 %

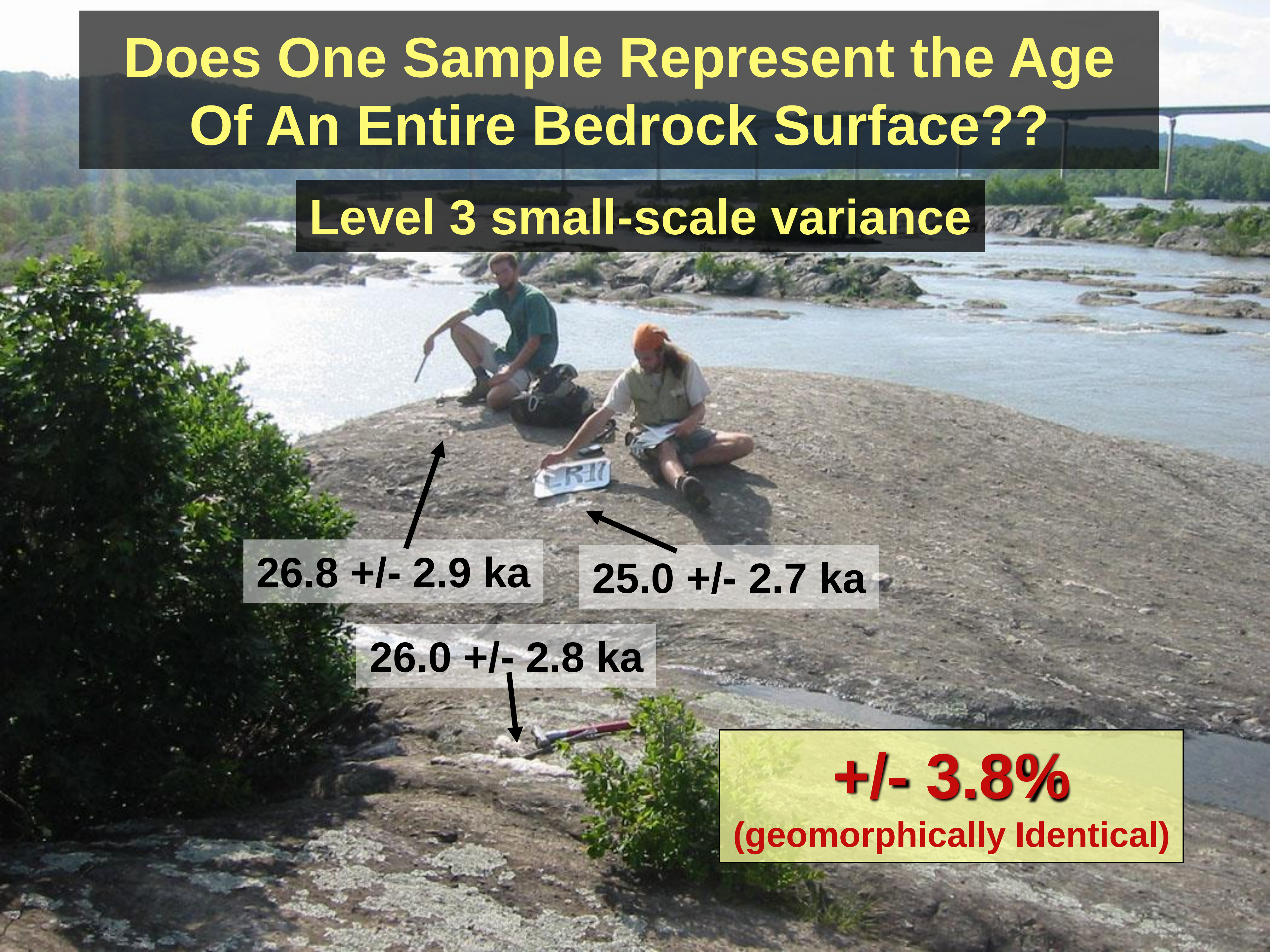
LR-37 17.4 +/- 1.9 ka

LR-37X 17.9 +/- 1.9 ka

+/- 1.9 %

Does One Sample Represent the Age Of An Entire Bedrock Surface??

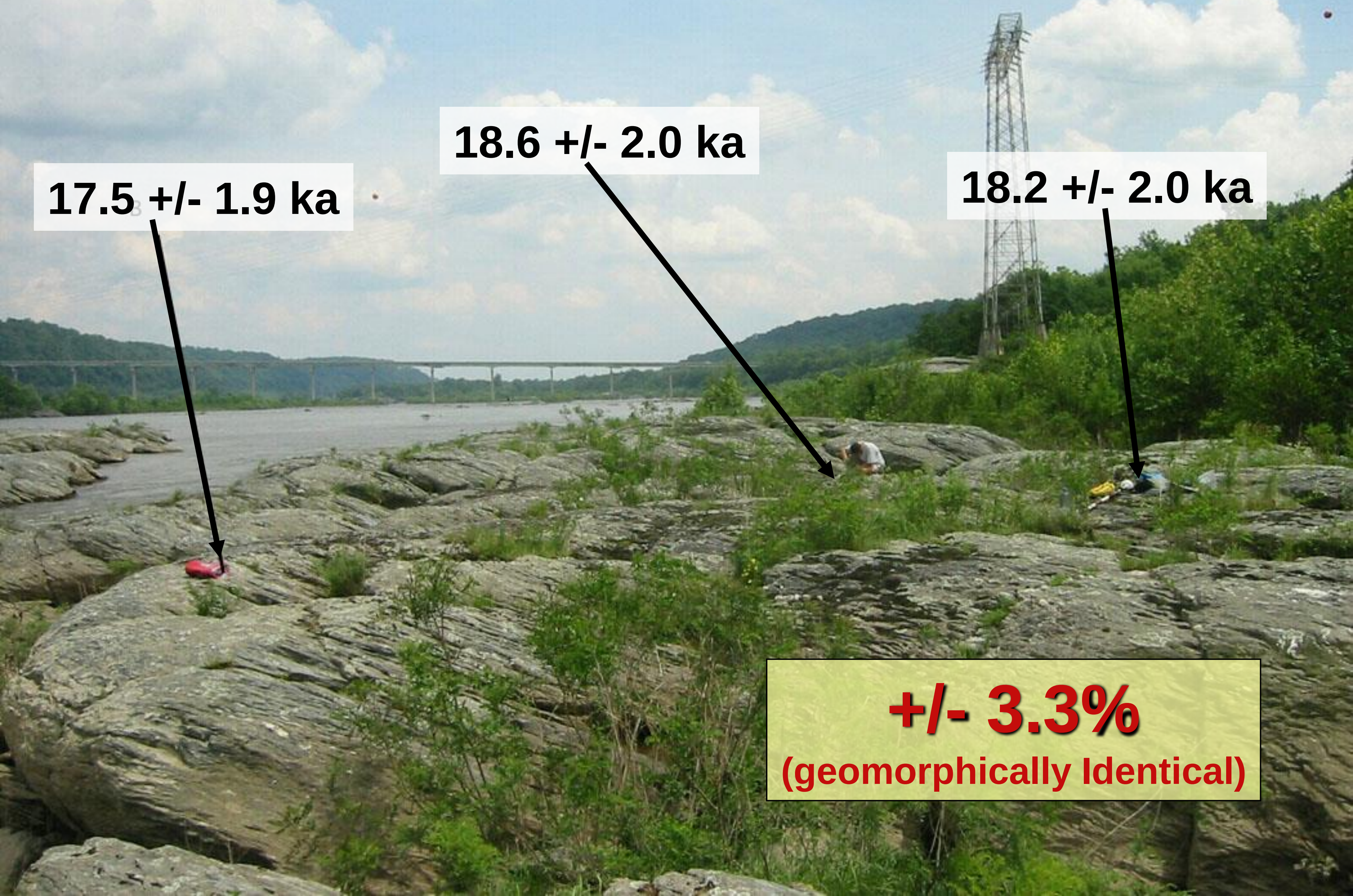
Level 3 small-scale variance



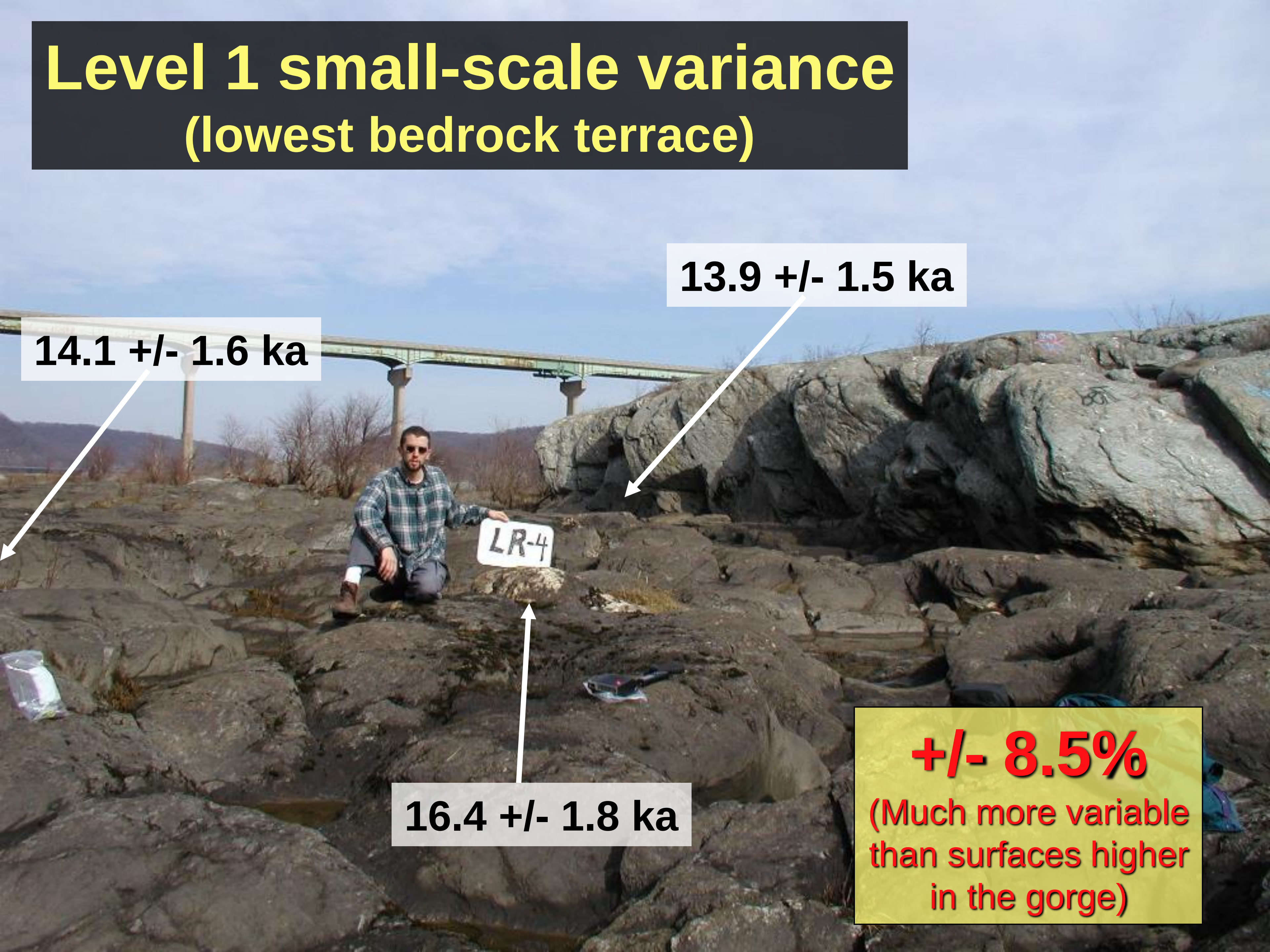
+/- 3.8%

(geomorphically Identical)

Level 2 small-scale variance



Level 1 small-scale variance
(lowest bedrock terrace)



Terrace Level 3: Longitudinal Incision Rate

No Relationship Between Distance and Model Age

Highest, Well Preserved Strath Terrace

Inferred River Gradient = **2.0 m/km**

$R^2 = 0.9$

Terrace Level 2:
Longitudinal Incision Rate

Mid-Level

Significant Age Gradient: 1.4 ky/km upstream

Older Ages Downstream
Knickpoint Retreat?

Inferred River Gradient = **1.5 m/km**
$R^2 = 0.9$

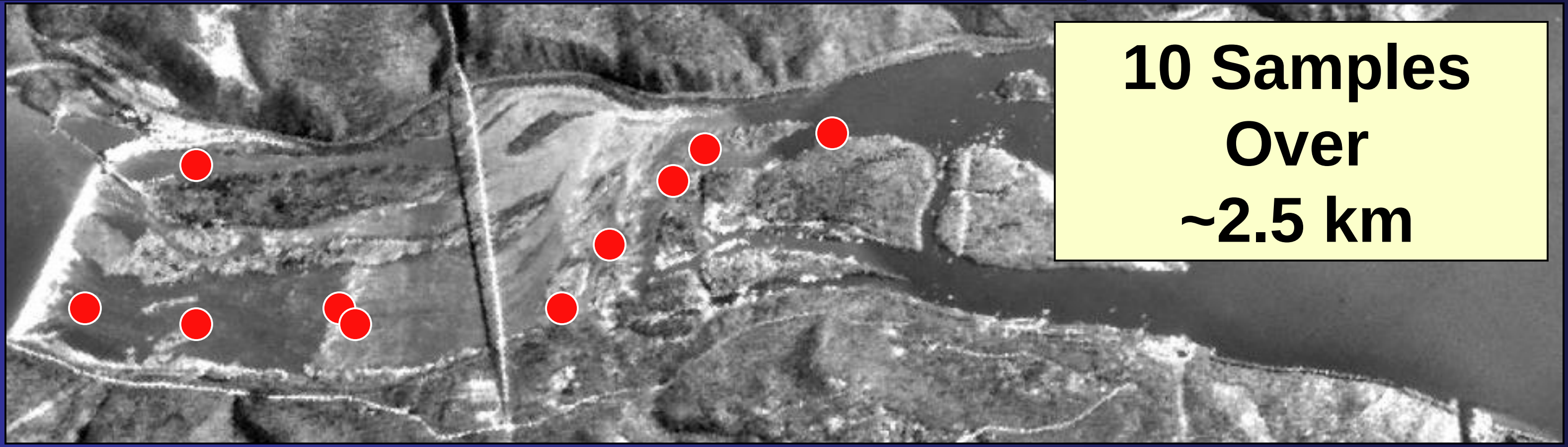
Terrace Level 1:

No Relationship Between Distance And Model Age

Inferred River Gradient

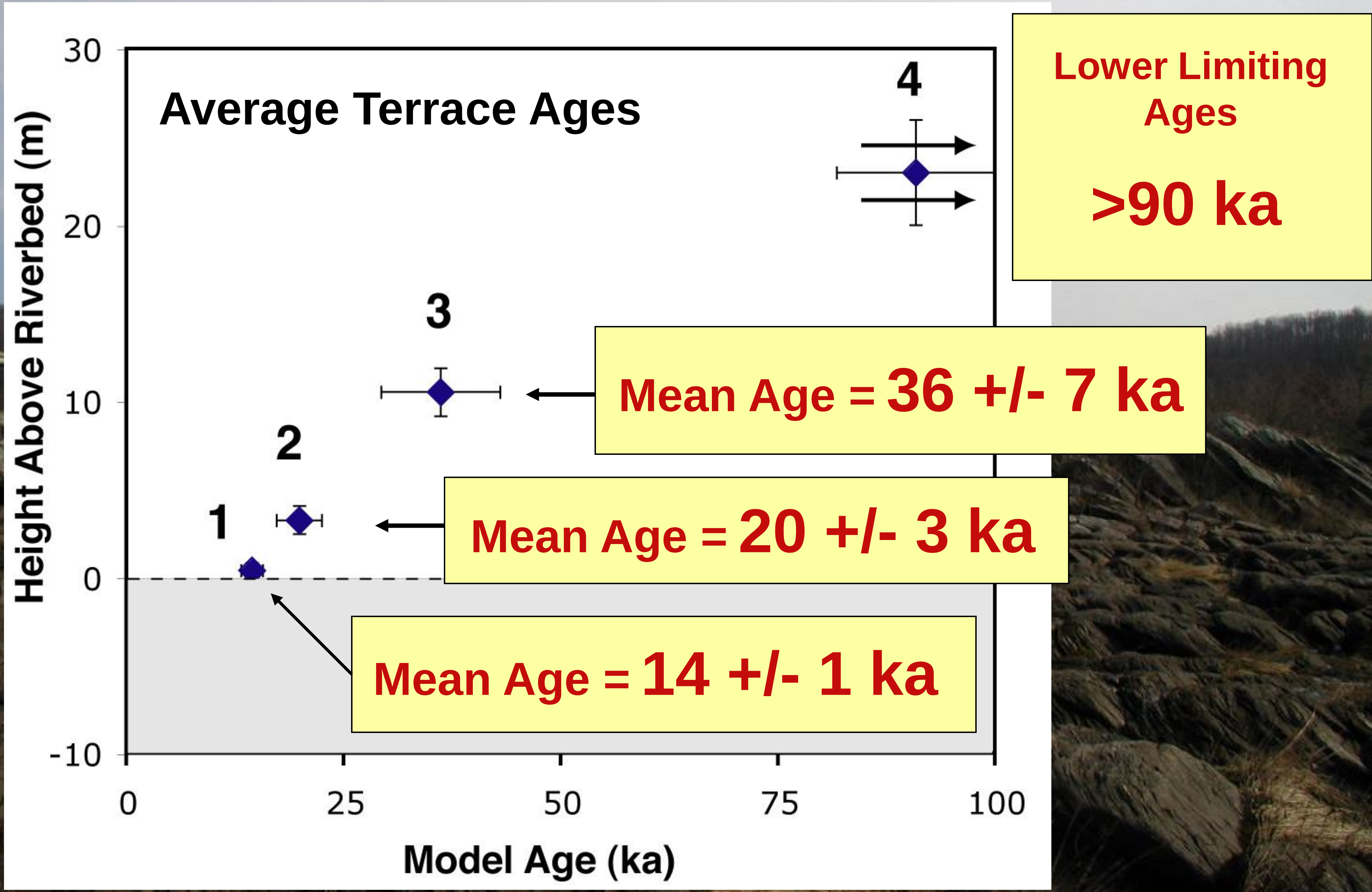
~1.5 m/km

R^2 = 0.9

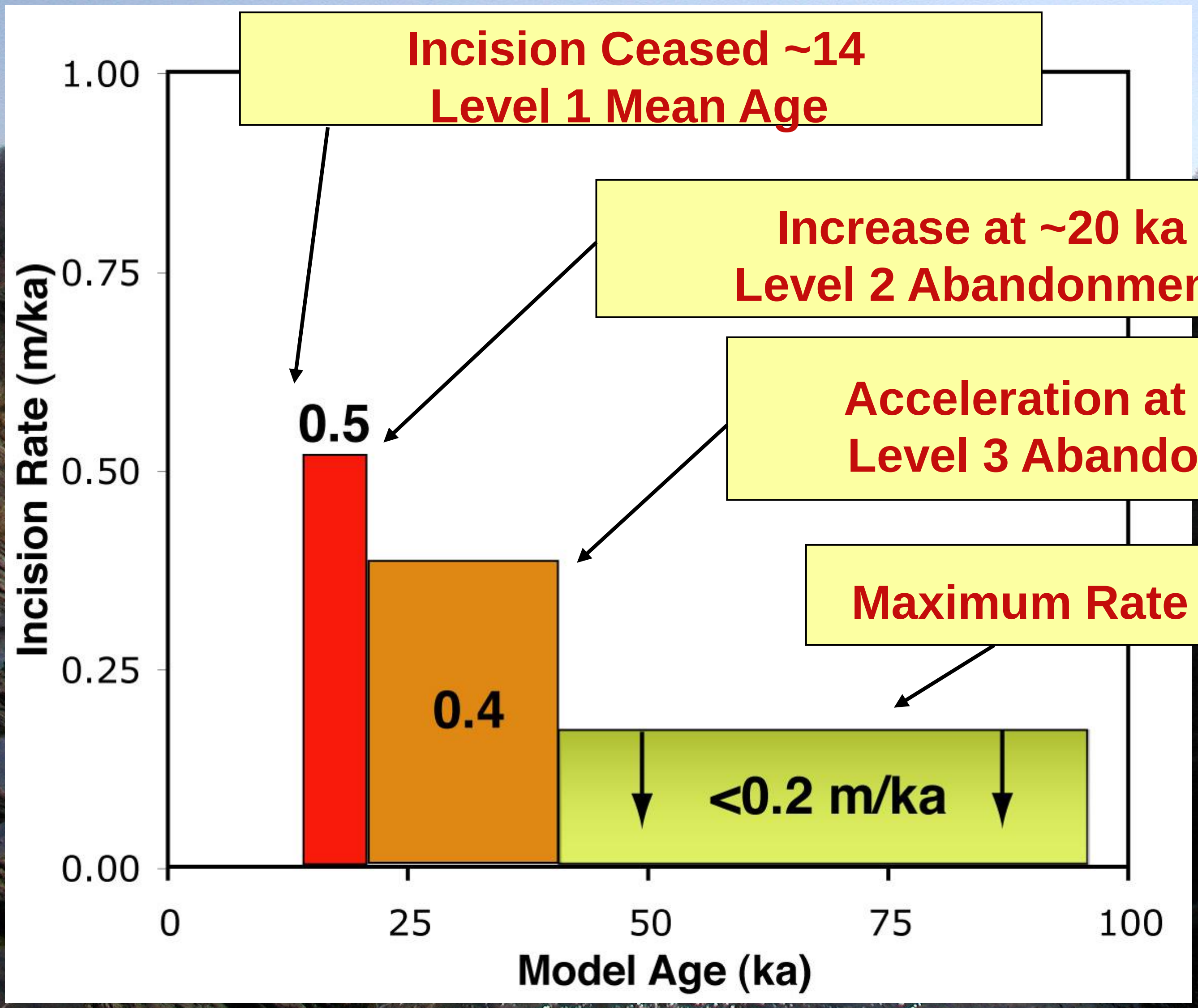


Timing and rate of bedrock incision within Holtwood Gorge

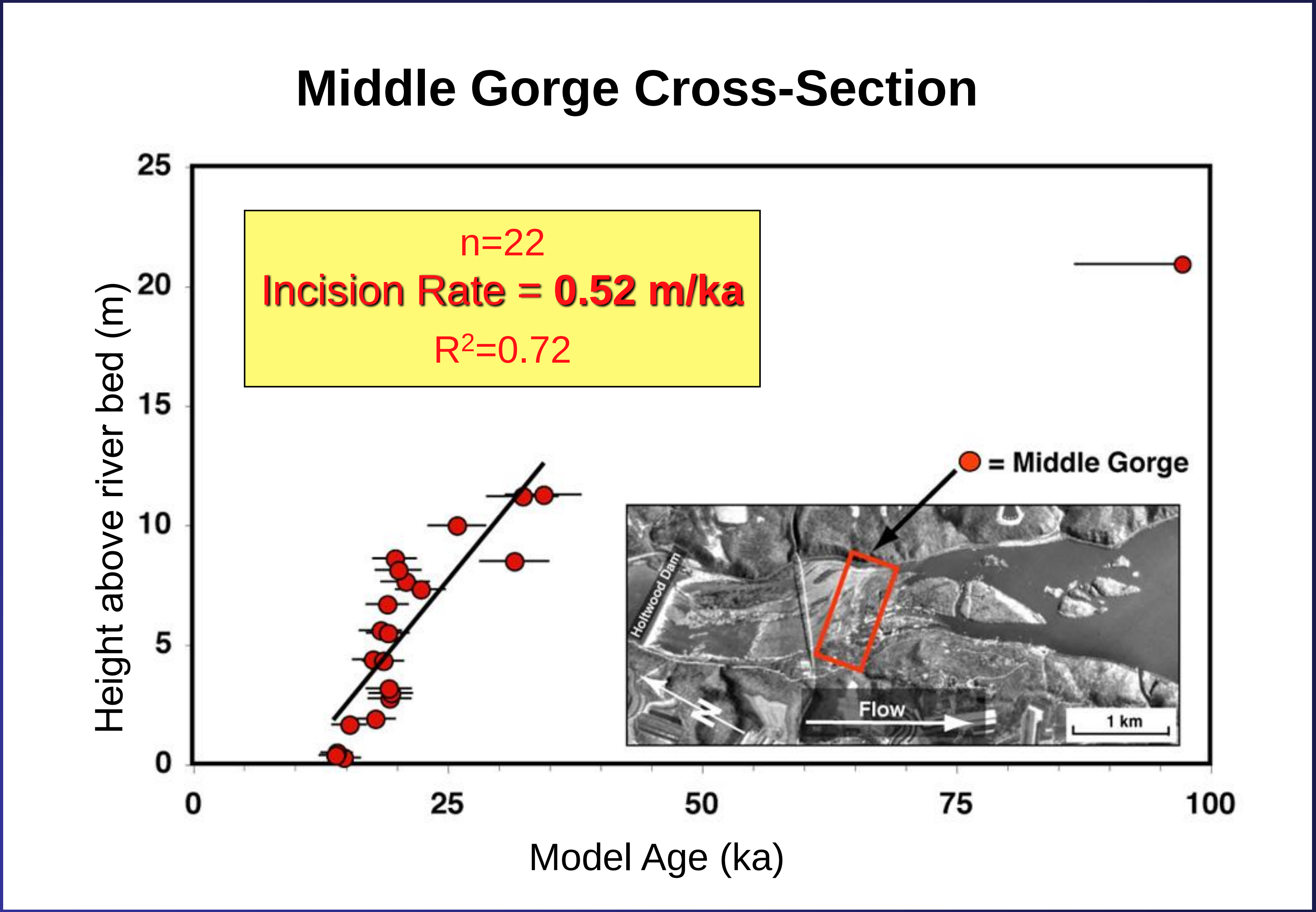
How Old Are The Holtwood Terraces??



When and How Quickly Did The Susquehanna River Incise??



Are Rates of Downcutting At Specific Locations Similar to Gorge Wide Averages?



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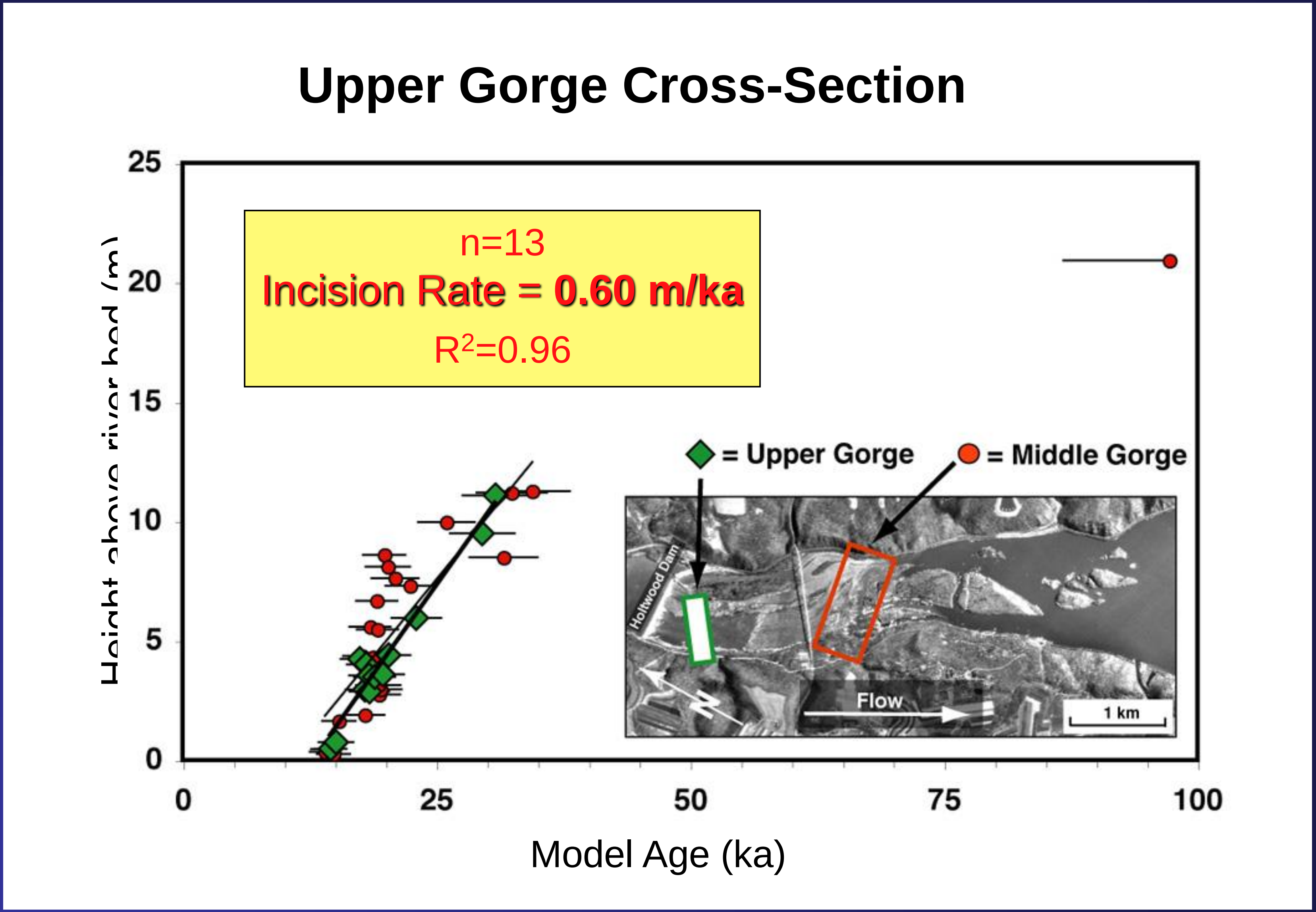
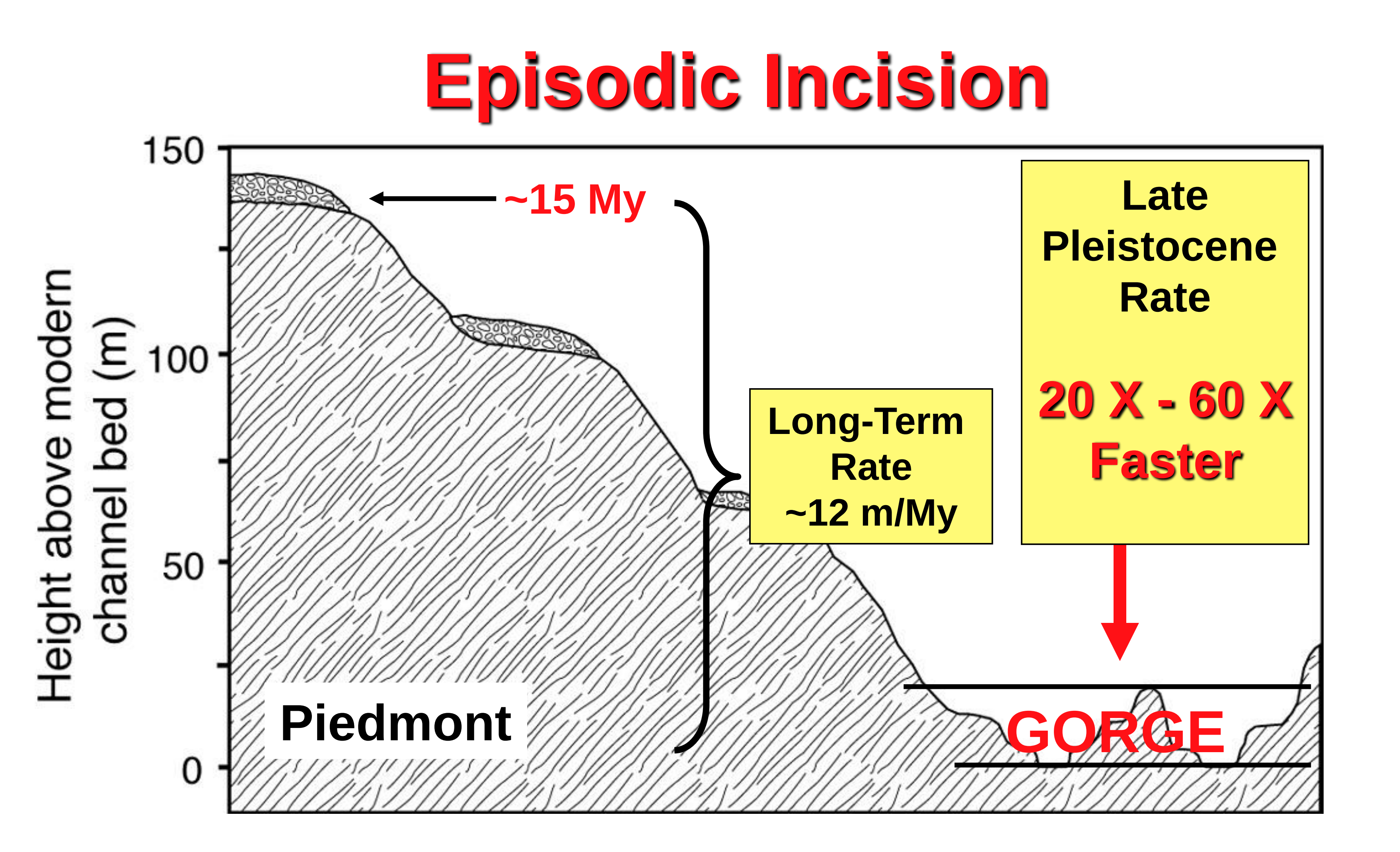


Long- vs. Short-Term Rates of Incision along the Susquehanna River



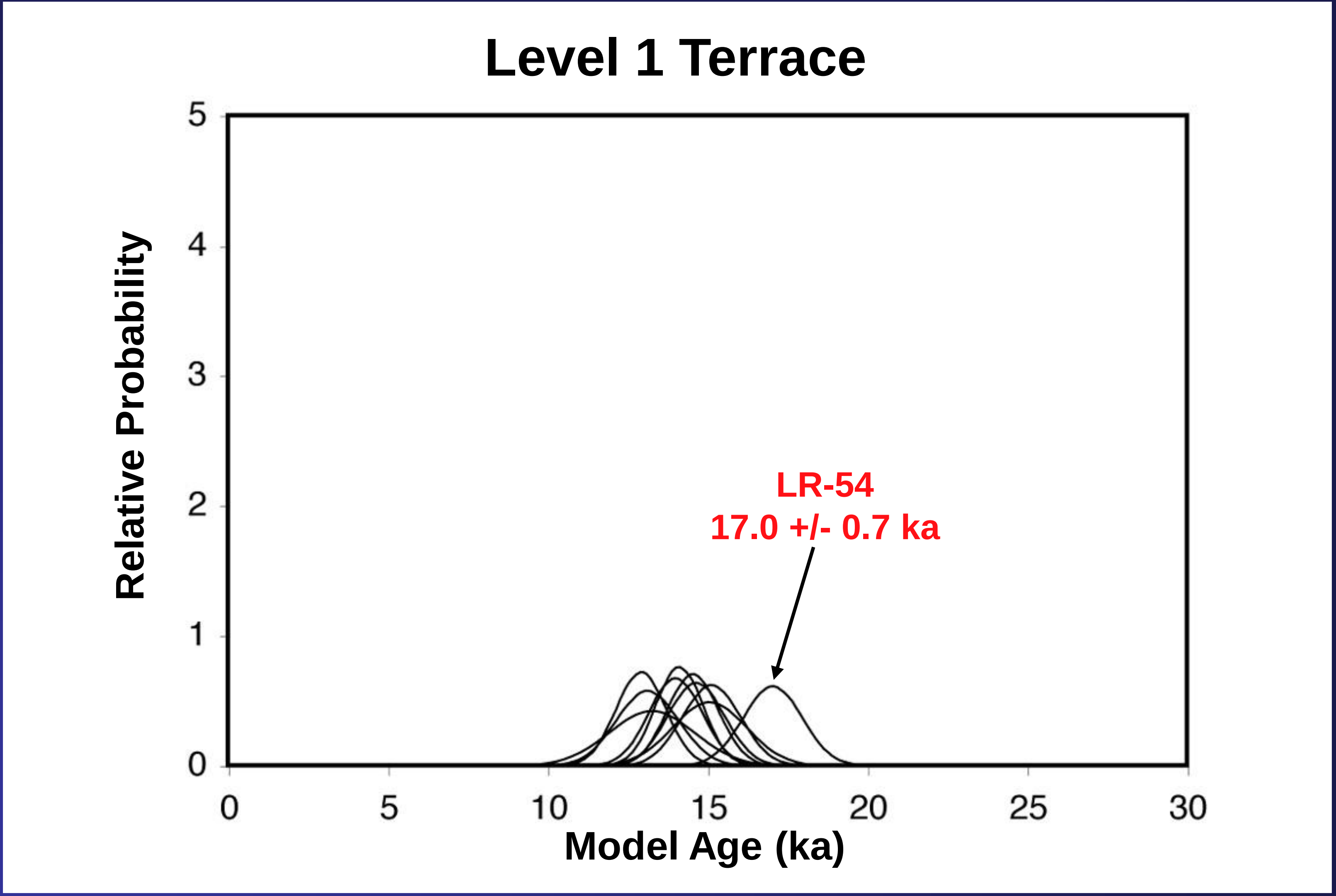
Rates in active regions measured with cosmogenic isotopes:

(Indus River, Himalayas)

1 to 12 m/ka
Driven primarily by uplift

An alternative approach to considering the timing of terrace abandonment:

(Probability Modeling: Balco *et al*., 2002)



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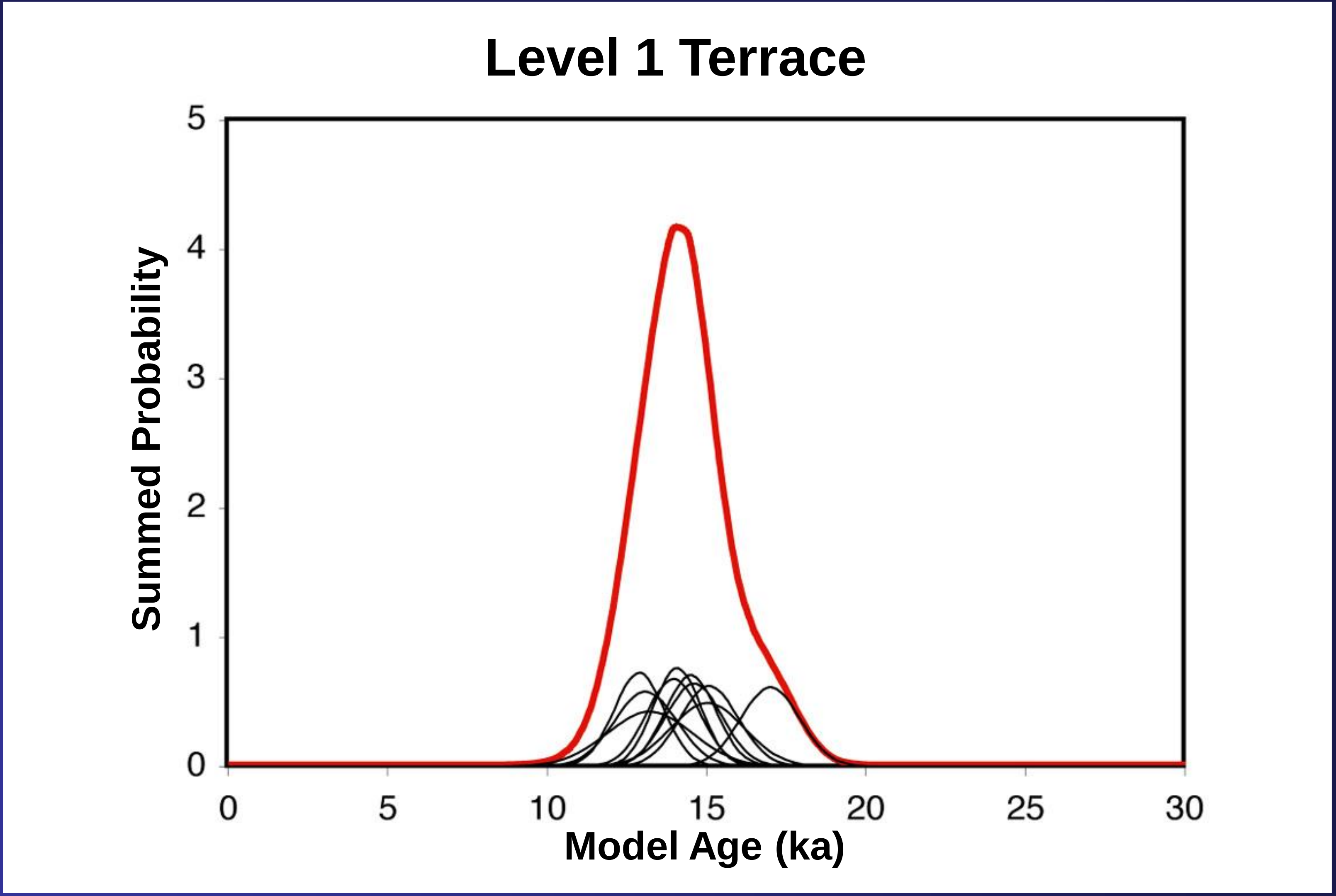

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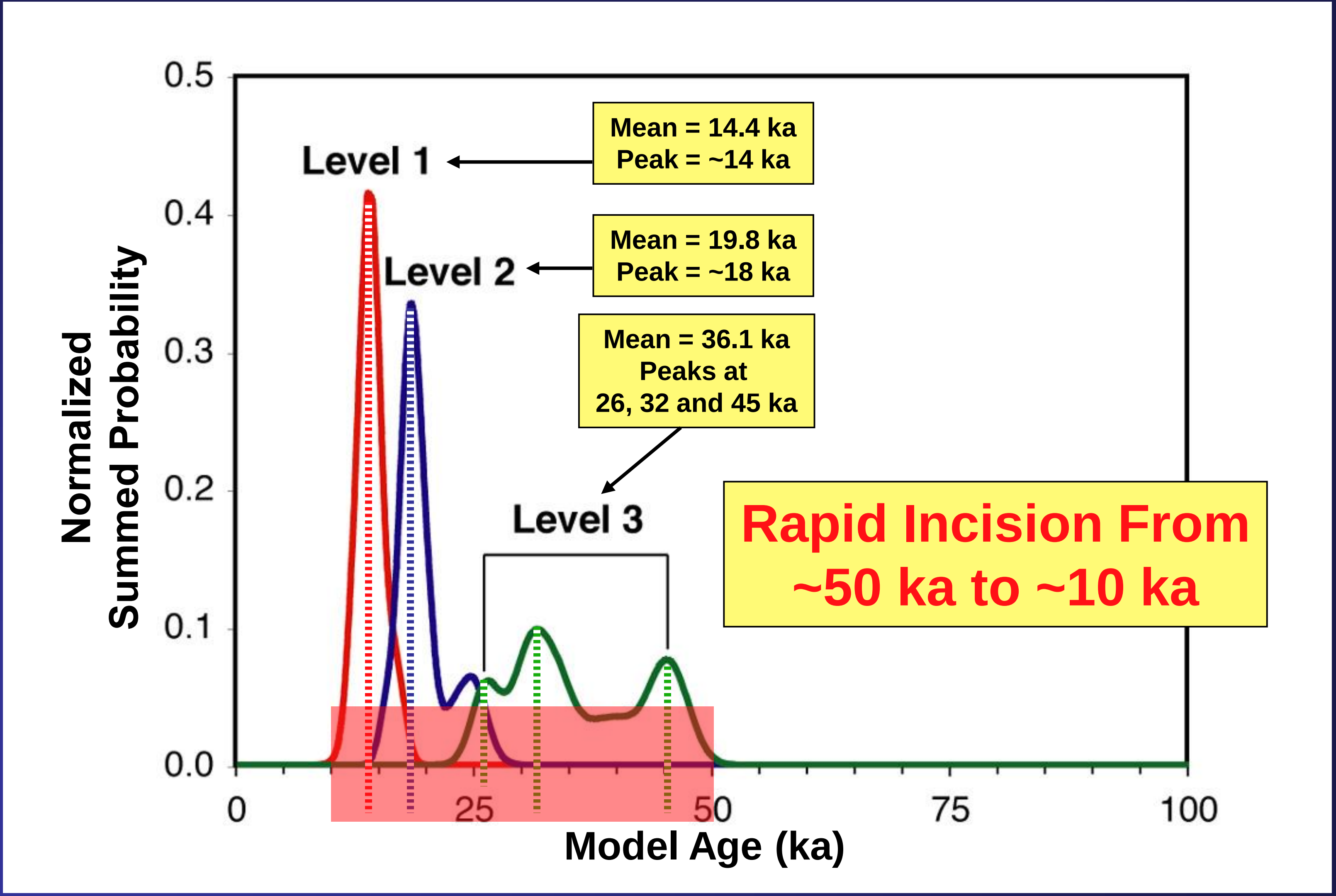
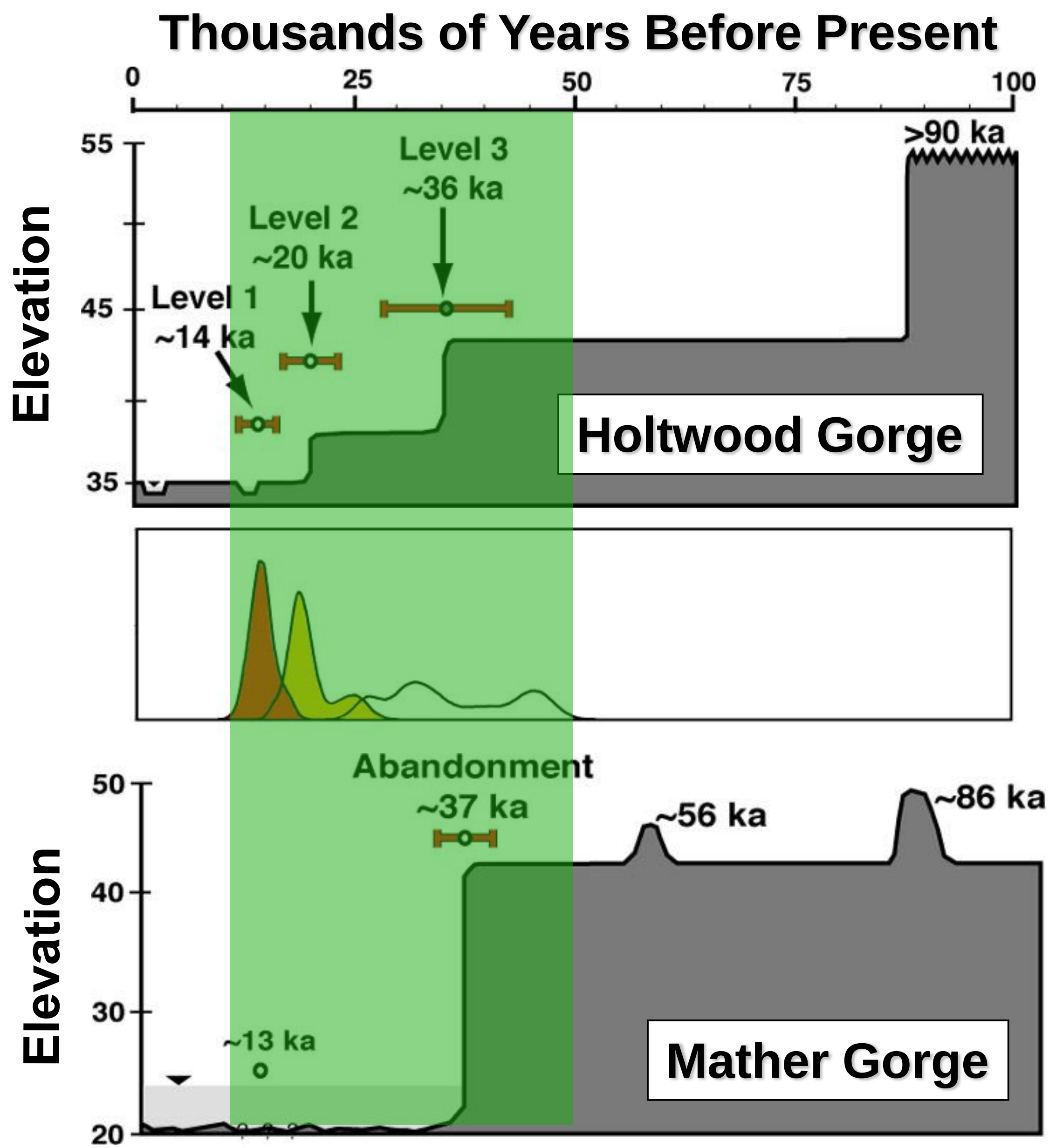


Potential Drivers of Rapid Late Pleistocene Incision

Similar Incision Histories



**Rapid Incision
From
~50 to 10 ka
At
0.4 to 0.6 m/ka**

**Rapid Incision
From
37 to 13 ka
At
0.5 to 0.8 m/ka**

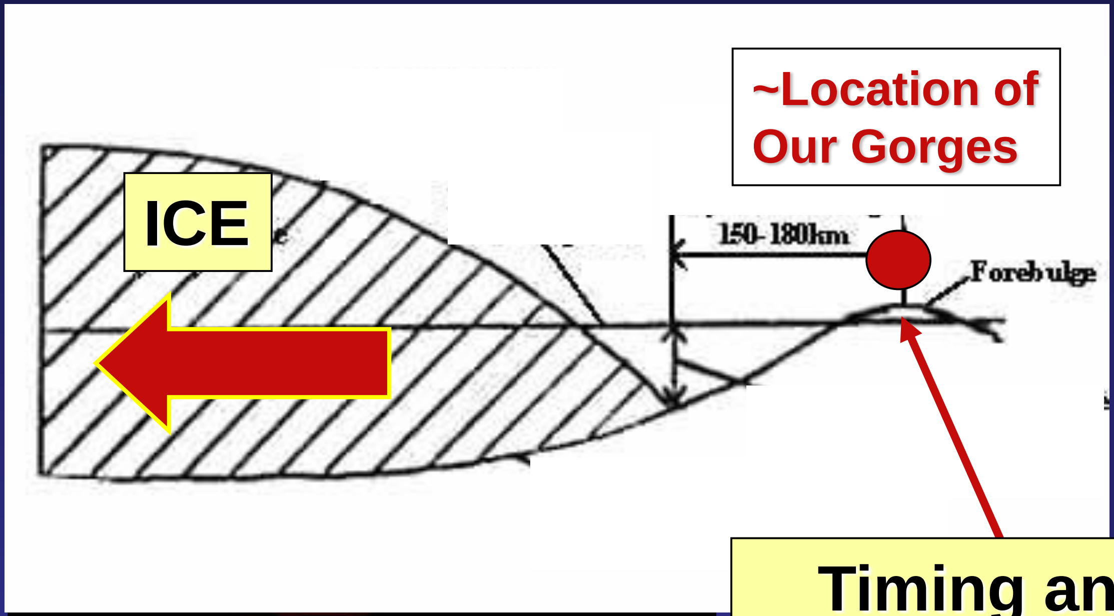
What Caused this Pulse of Late Pleistocene Incision?

- Glaciated Susquehanna Basin
- Unglaciated Potomac Basin
- Similar Timing
- Similar Rate

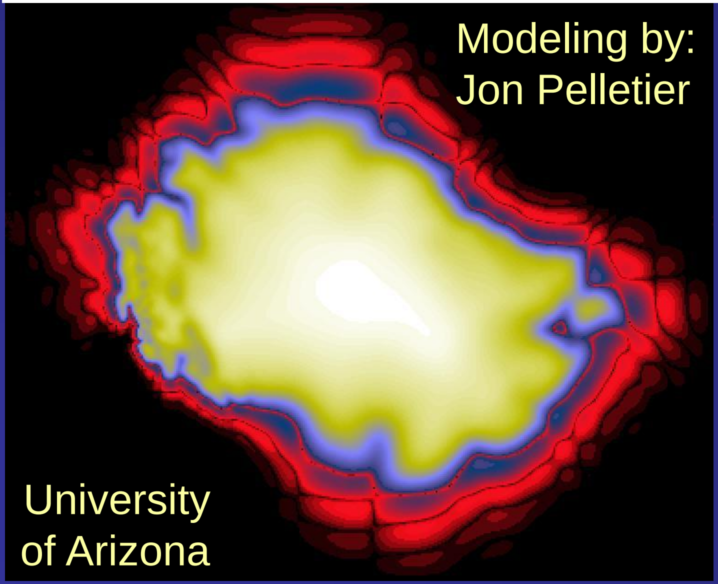
- **Regional Forcings:**

- Land-Level
- Base-Level
- Global and Regional Climate

Land Level Change…
(The Growing Glacial Forebulge)



- Crustal Response to mantle displacement by advancing ice load



Timing and extent uncertain

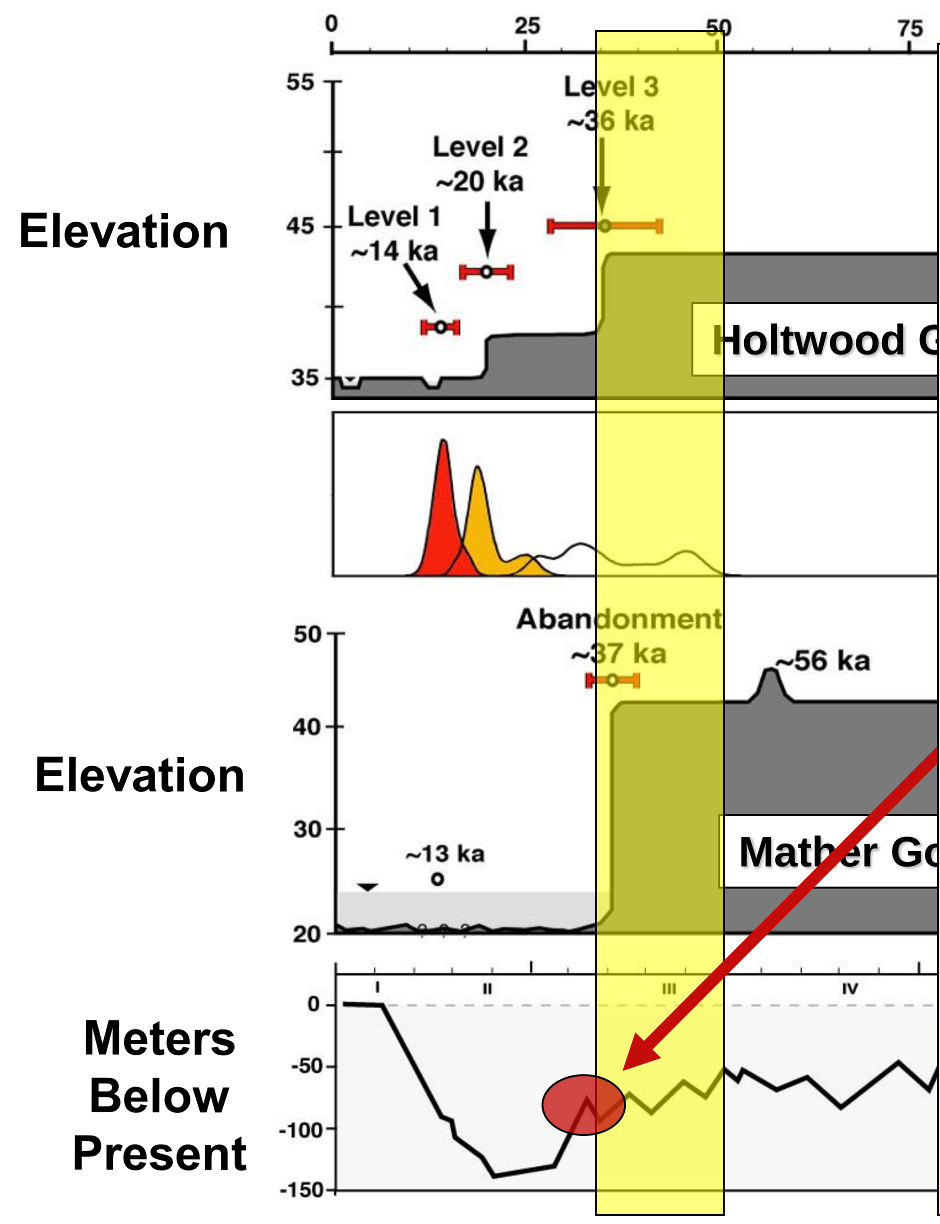
Where was the ice front?

Probably didn't initiate Incision, But likely helped maintain it

Increased River Gradients

Base Level Change…

(Global Sea-Level Through The Last Glacial Cycle)



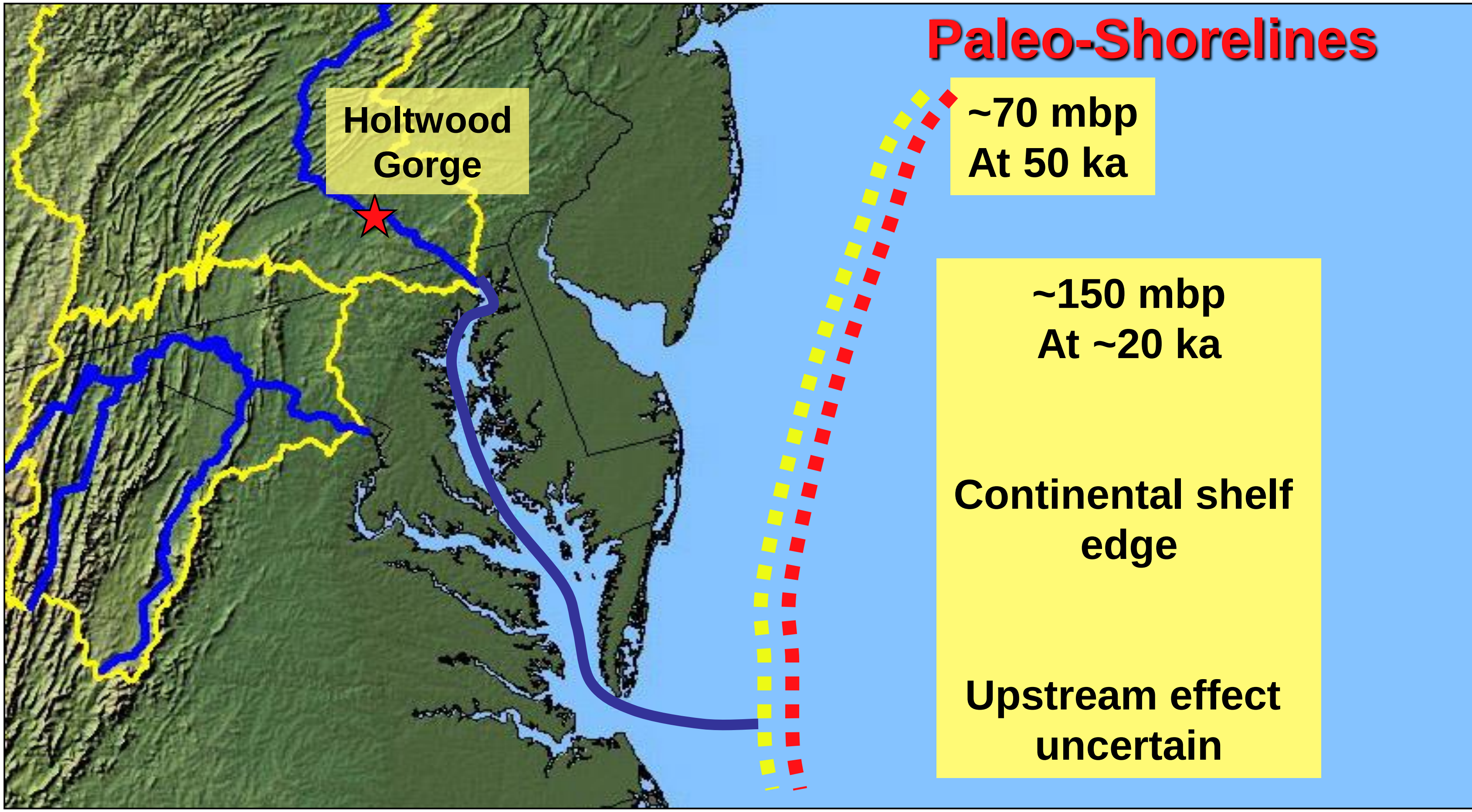
Timing of Sea-Level Fall Uncertainties

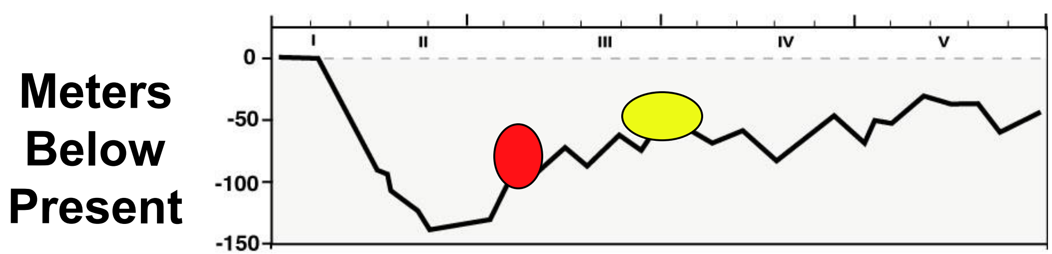
Exposure Age Modeling Uncertainties

Rate and Process of Upstream Translation Through Bedrock Not Know

Base Level Change…

(Global Sea-Level Through The Last Glacial Cycle)

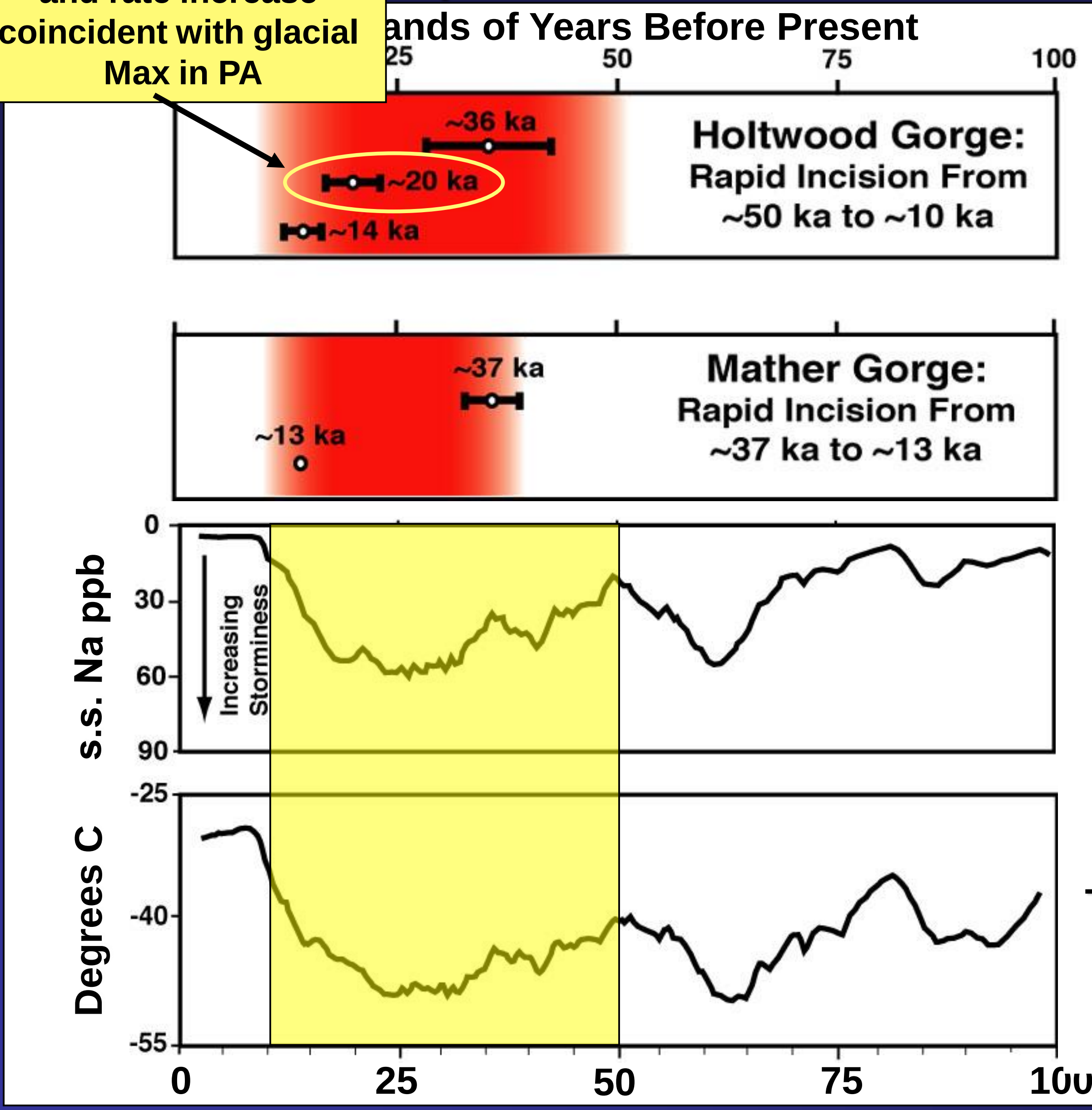




Mean Global Sea-Level
(Huon Peninsula)

Global Climate Change…
(GISP2 ice core records)

Terrace formation and rate increase coincident with glacial Max in PA



Susquehanna River

Potomac River

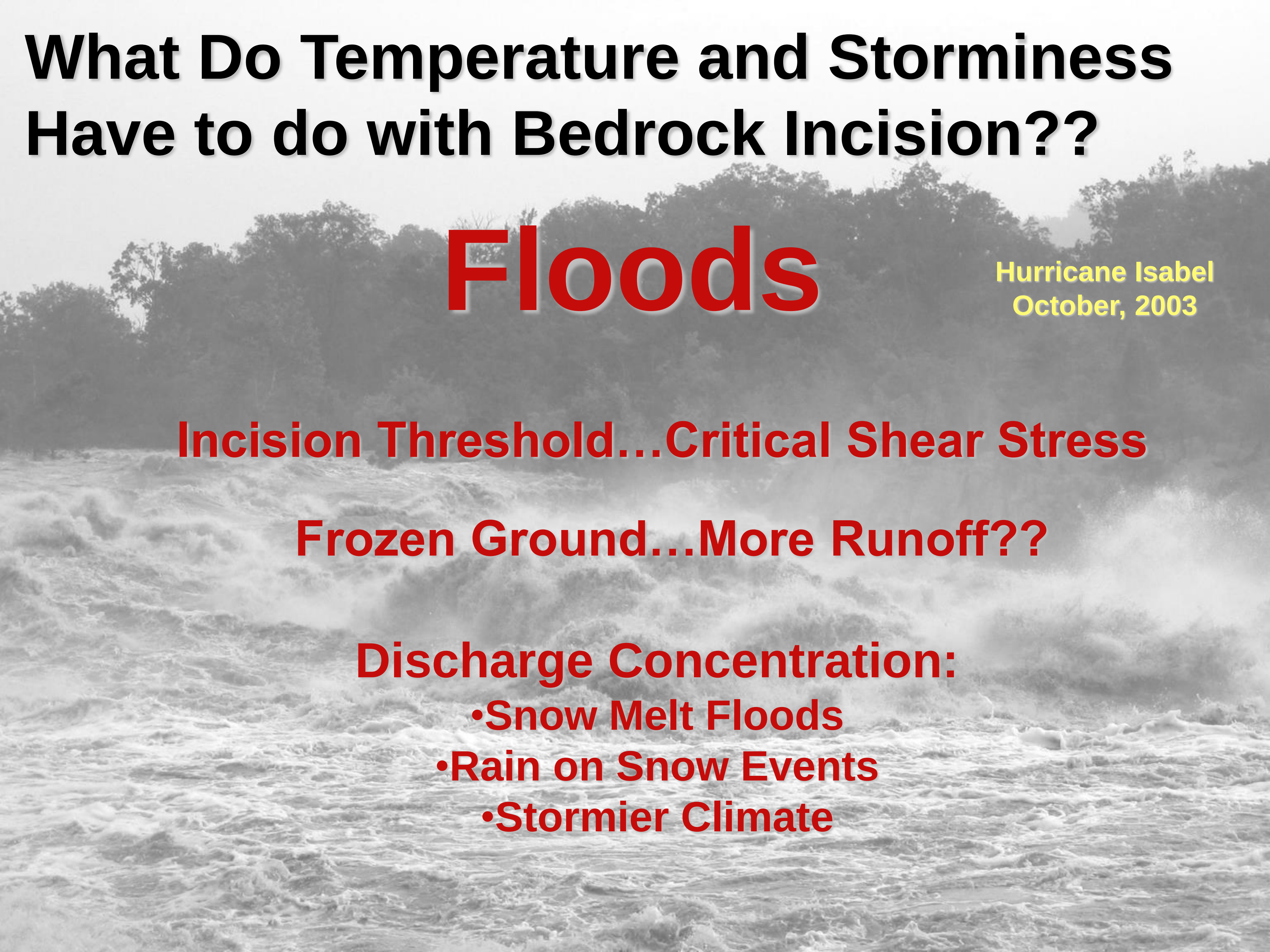
Paleostorminess

Storminess in Northeast Through Holocene (Noren et al., 2003)

Paleotemperature

Temperature trends correlate To Florida (Grimm et al.), And Blue Ridge (Litwin et al., 2004)

What Do Temperature and Storminess Have to do with Bedrock Incision??



Hurricane Isabel
October, 2003

Floods

Incision Threshold…Critical Shear Stress

Frozen Ground…More Runoff??

Discharge Concentration:

- Snow Melt Floods
- Rain on Snow Events
- Stormier Climate

Conclusions

Bedrock strath terraces record a pulse of rapid incision

Downcutting increased between ~50 and ~35 ka;
Incision ceased near the Pleistocene/Holocene transition

Influence of glacial retreat on Susquehanna River;
But regional first order drivers for the
initiation of incision on both rivers.

Correlation to GISP2 climate proxy records

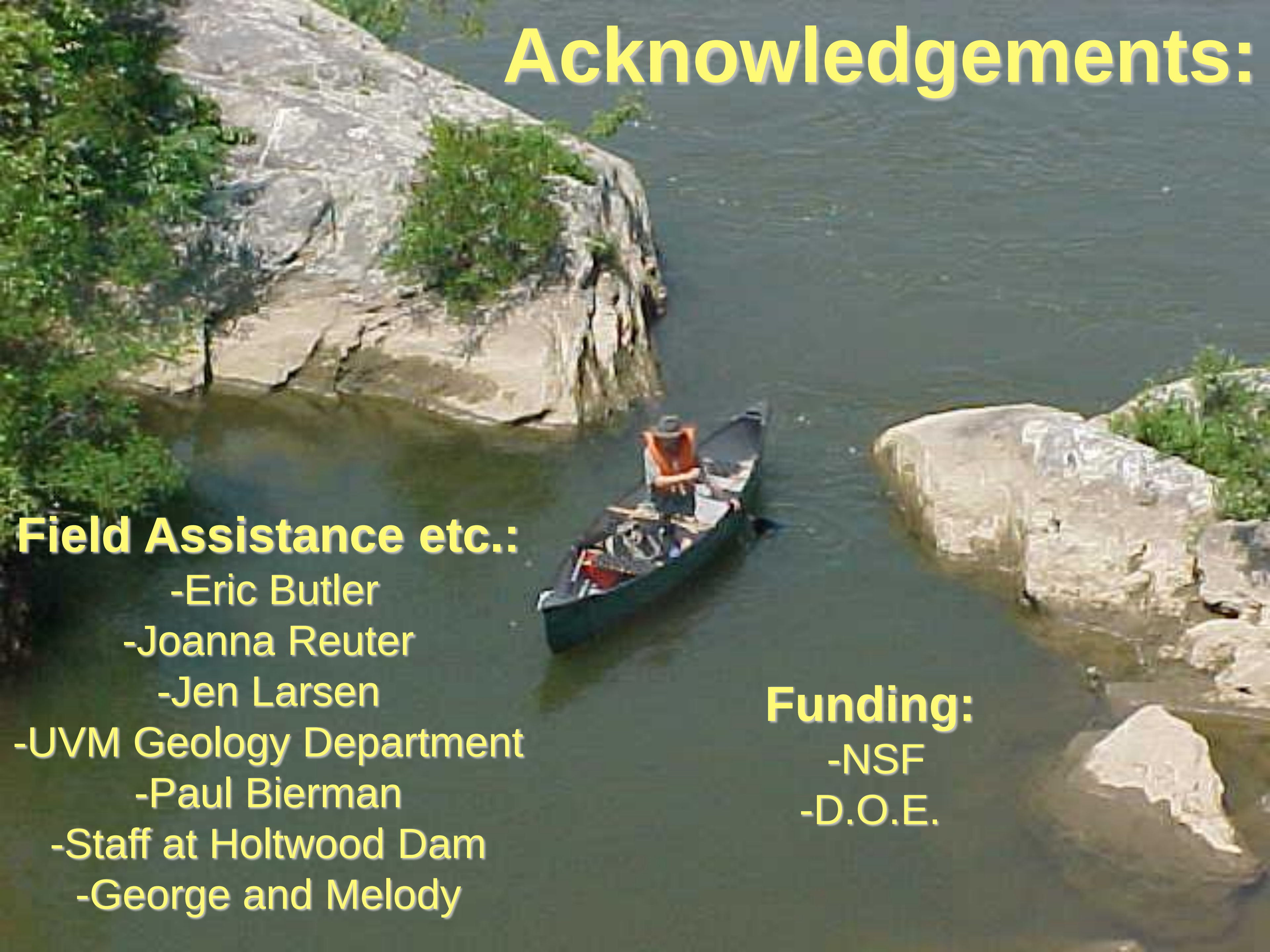
Implications and Future Research

^{10}Be dating is a useful tool for investigating the tempo and style of bedrock channel incision around the globe

The episode of incision measured in Holtwood Gorge represents one pulse in an ongoing period of river adjustment operating over geologic time scales

This study just scratches the surface:

- Similar approach on other major Appalachian drainages
- Tributary response to changing boundary conditions and landscape conectivity
- Many questions regarding climate driven process rates still remain



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Field Assistance etc.:

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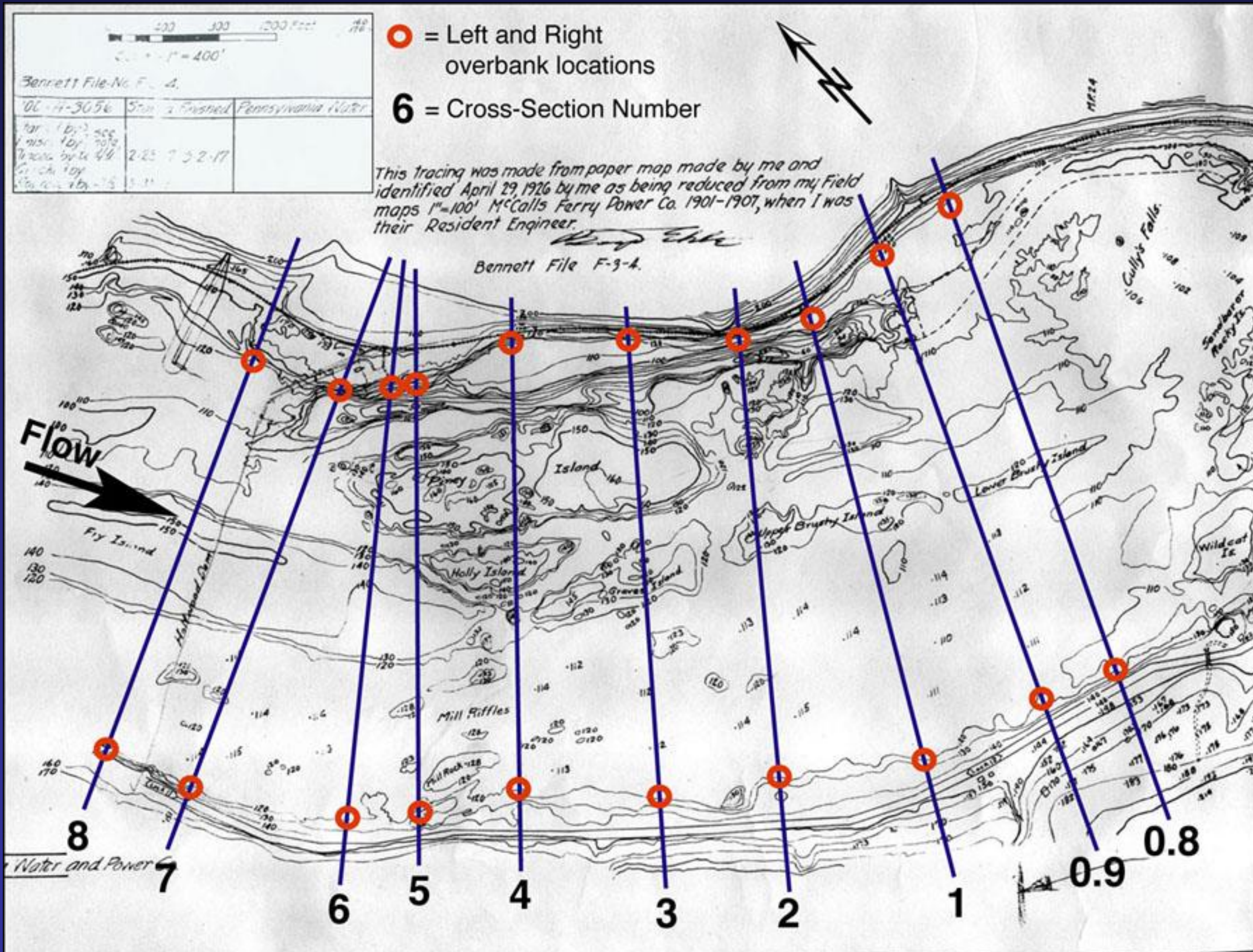
-Paul Bierman
-Staff at Holtwood Dam
-George and Melody

Funding:

-NSF
-D.O.E.

Hecras Modeling:



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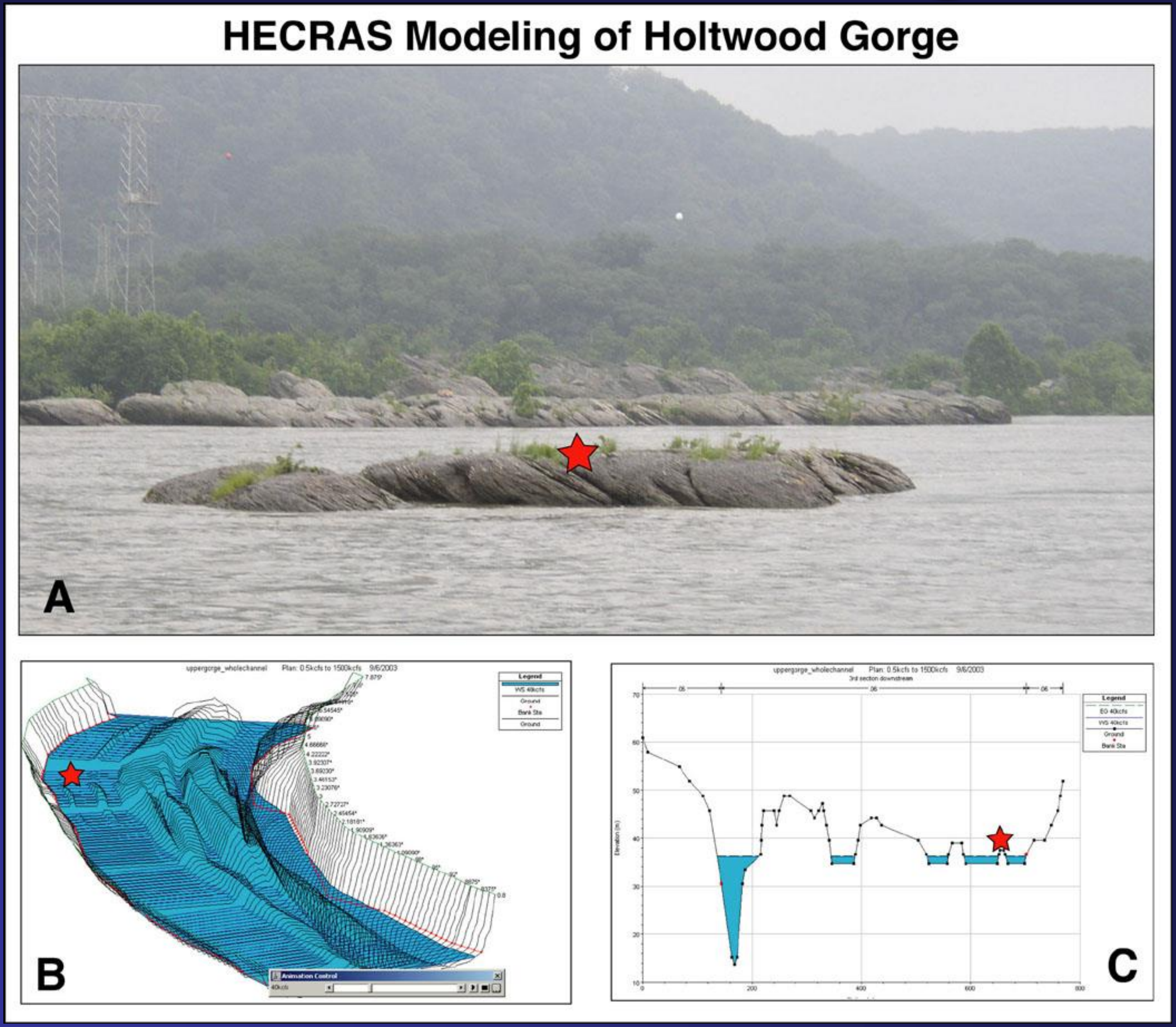
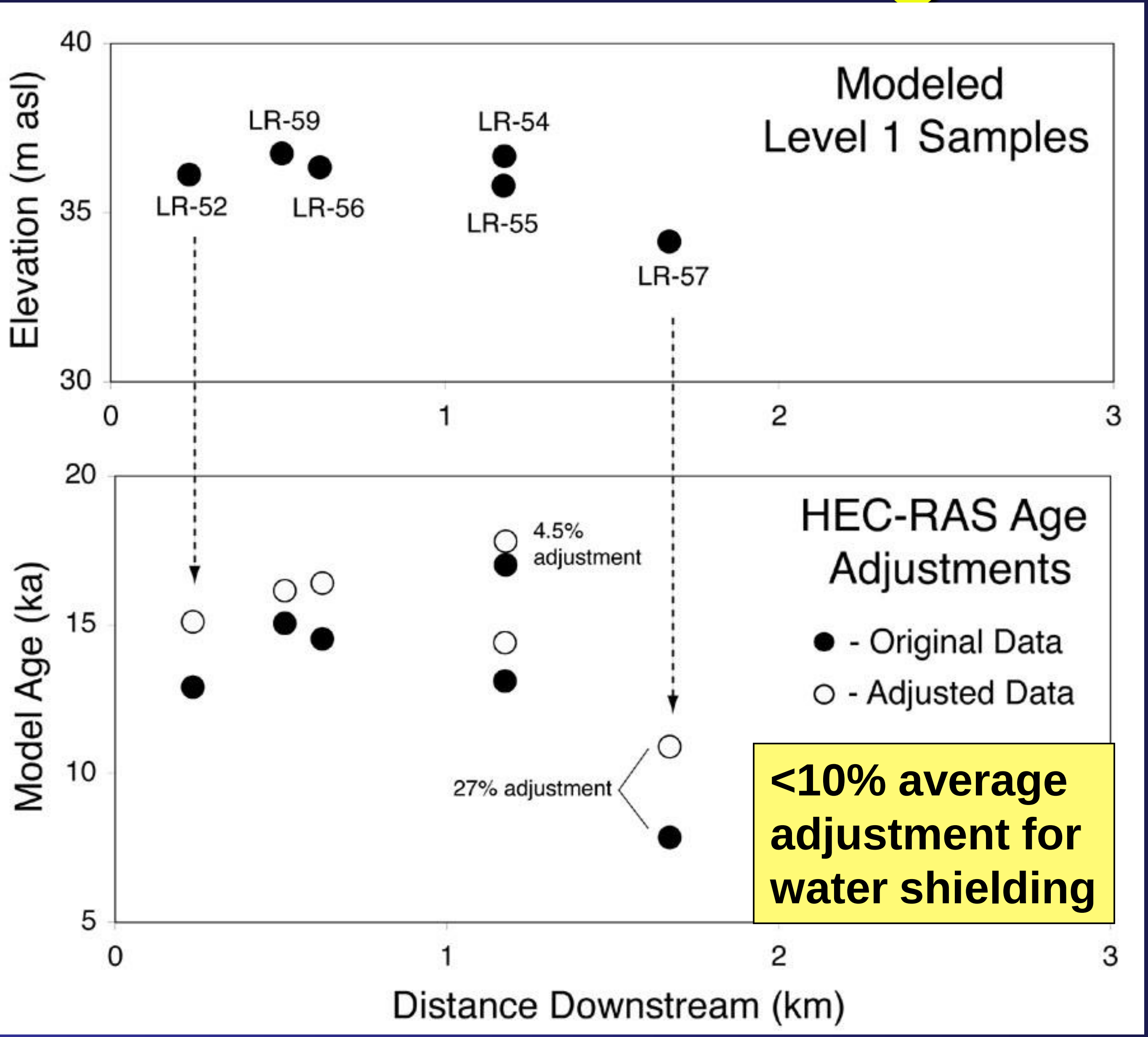


Hecras Modeling:



<10% average adjustment for water shielding

Hecras Modeling:

Summary of Age Adjustments Made to Specified Samples Resulting From HECRAS Modeling of Holtwood Gorge

LR-52		LR-56		LR-54		LR-55		LR-57	
elevation	36.112	elevation	36.339	elevation	36.674	elevation	35.797	elevation	34.151
level	1	level	1	level	1	level	1	level	1
total possib	25568	total poss	25568	total poss	25568	total poss	25568	total poss	25568
acutal	21868.38	actual	23276.78	actual	24400.41	actual	23260.77	actual	18712.33
%total	85.53026	% total	91.03873	% total	95.43341	% total	90.9761	% total	73.18651
model age	12.9	model age	14.9	model age	17	model age	13.1	model age	7.9
adj age	15.08238	adjusted ag	16.36666	adjusted ag	17.81347	adjusted ag	14.39939	adjusted ag	10.79434

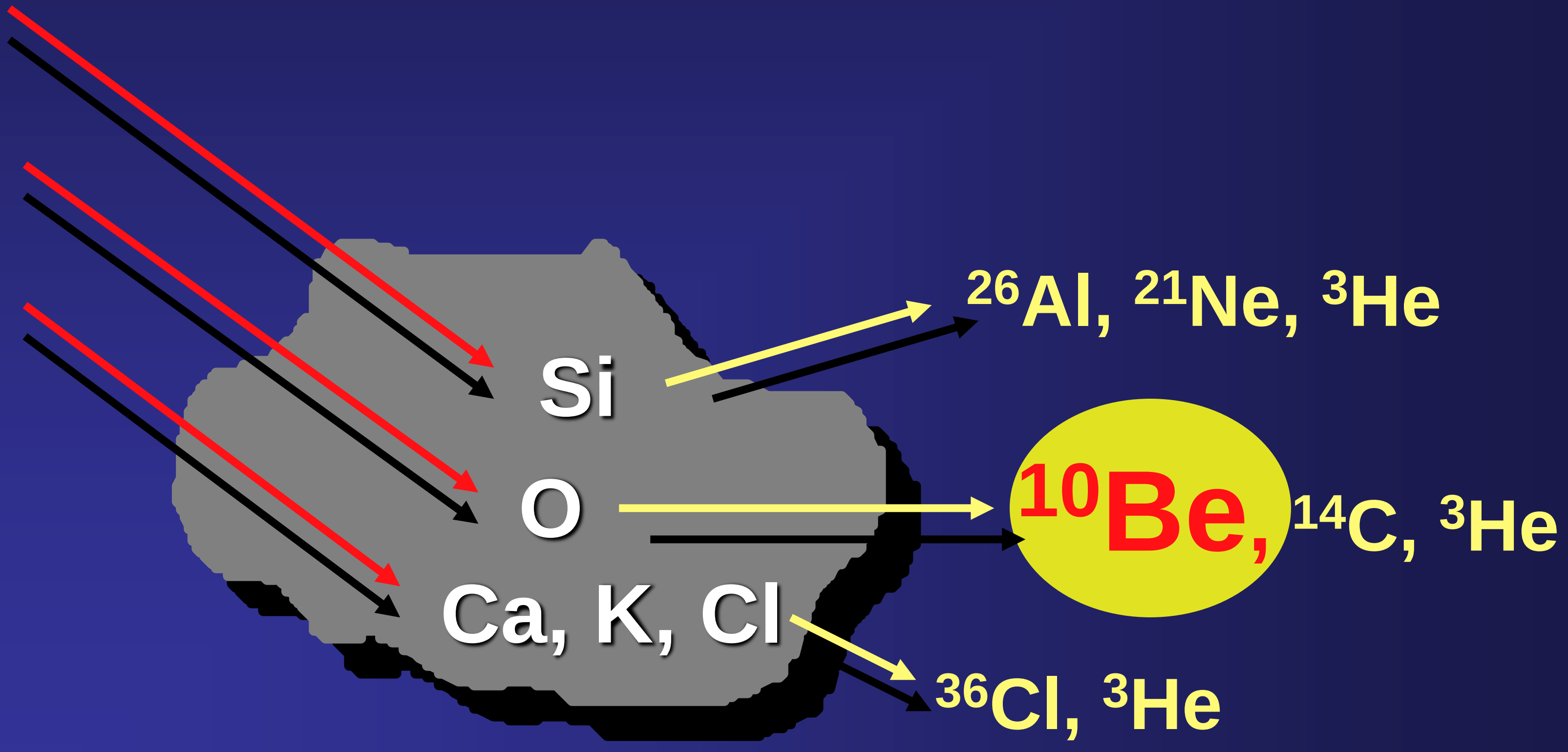
LR-59		LR-34		LR-36ave		LR-29		LR-38	
elevation	36.747	elevation	39.5	elevation	40.04	elevation	47.05	elevation	45.3
level	1	level	2	level	2	level	3	level	3
total poss	25568	total poss	25568	total poss	25568	total poss	25568	total poss	25568
actual	23837.71	actual	25280.89	actual	25388.96	actual	25567.25	actual	25565.84
% total	93.2326	% total	98.87709	% total	99.29977	% total	99.99708	% total	99.99157
model age	15.05	model age	19.66	model age	17.6	model age	30.78	model age	29.45
adjusted ag	16.14242	adjusted ag	19.88327	adjusted ag	17.72411	adjusted ag	30.7809	adjusted ag	29.45248

Summary of HECRAS Adjustments for Level 1 Samples

	Original Model Age (ka)	Adjusted Model Age (ka)	Difference (ka)
LR-52	12.9	**15.1**	2.2
LR-56	14.9	**16.4**	1.5
LR-54	17.0	**17.8**	0.8
LR-55	13.1	**14.4**	1.3
LR-57	7.9	**10.8**	2.9
LR-59	15.5	**16.1**	0.6
mean	13.6	**15.1**	1.5
stdev	3.2	**2.4**	
% of mean	23.4	**16.0**	7.4

Modeling explains ~32% of the model Age variance between Level 1 samples

Cosmic ray bombardment *in situ*



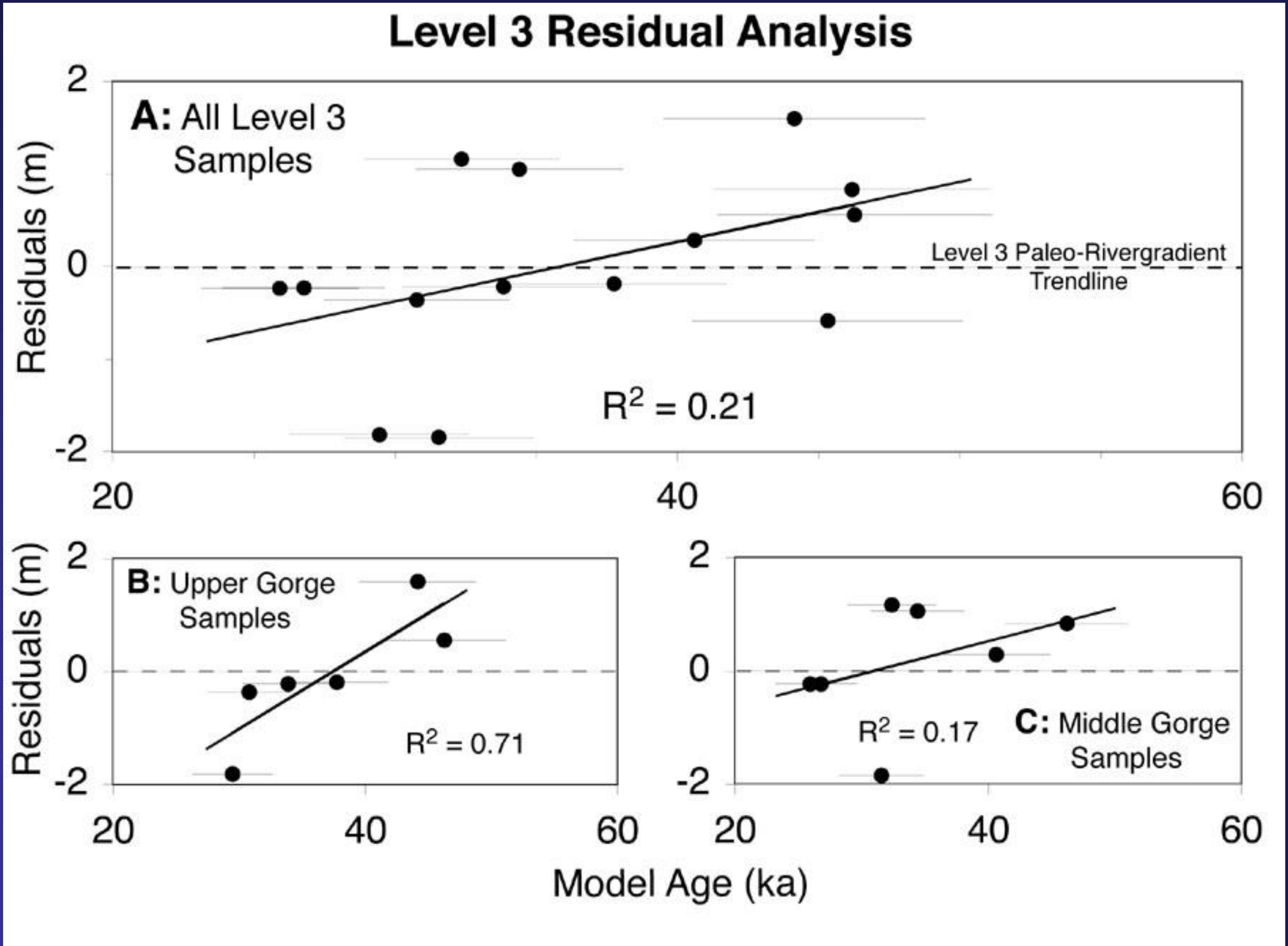
Inferred Paleo River Gradients

Level 3 Gradient = 2.0 m/km

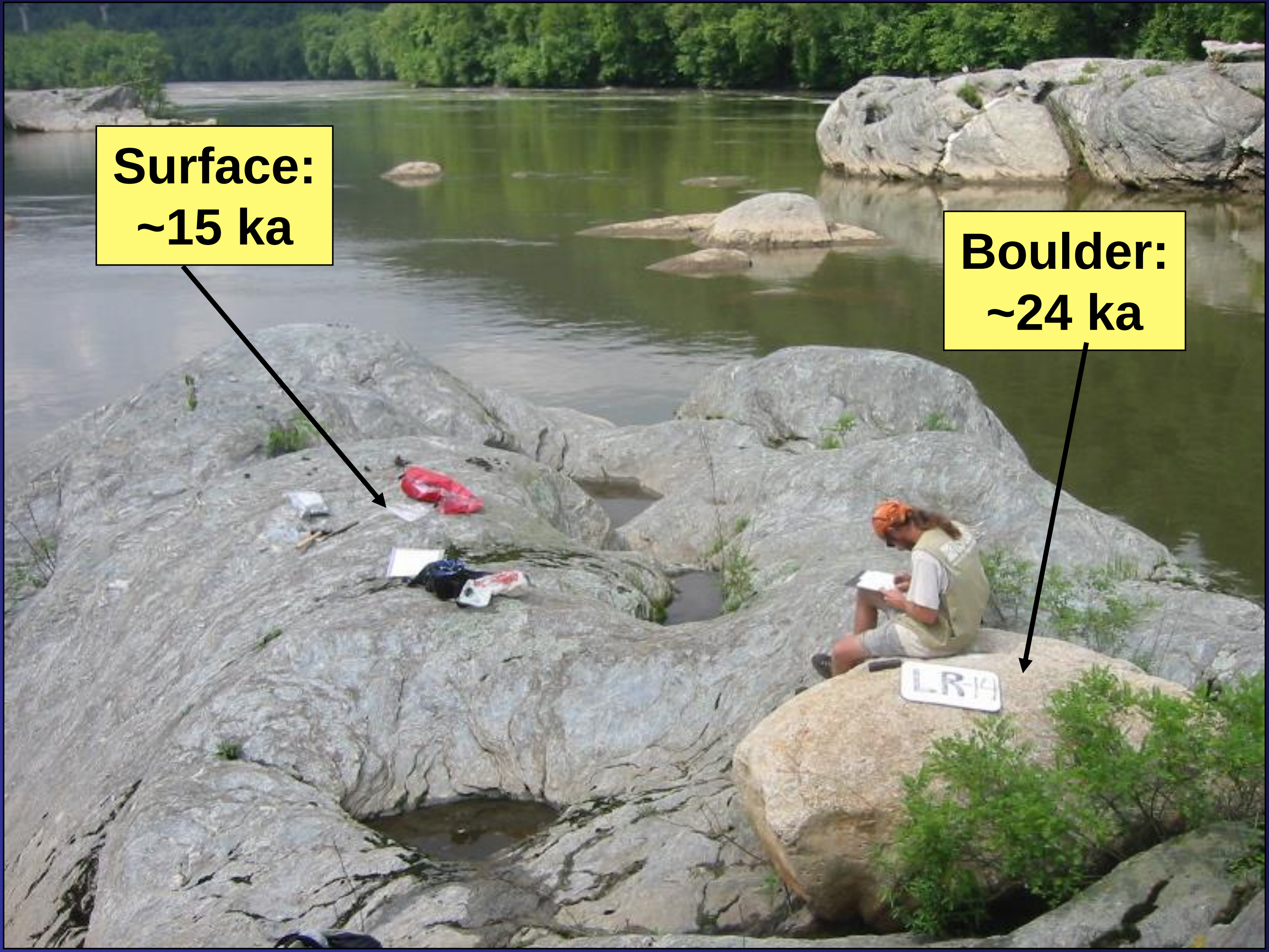
Level 2 Gradient = 1.5 m/km

Level 1 Gradient = 1.5 m/km

Residual Analysis:



Boulders:



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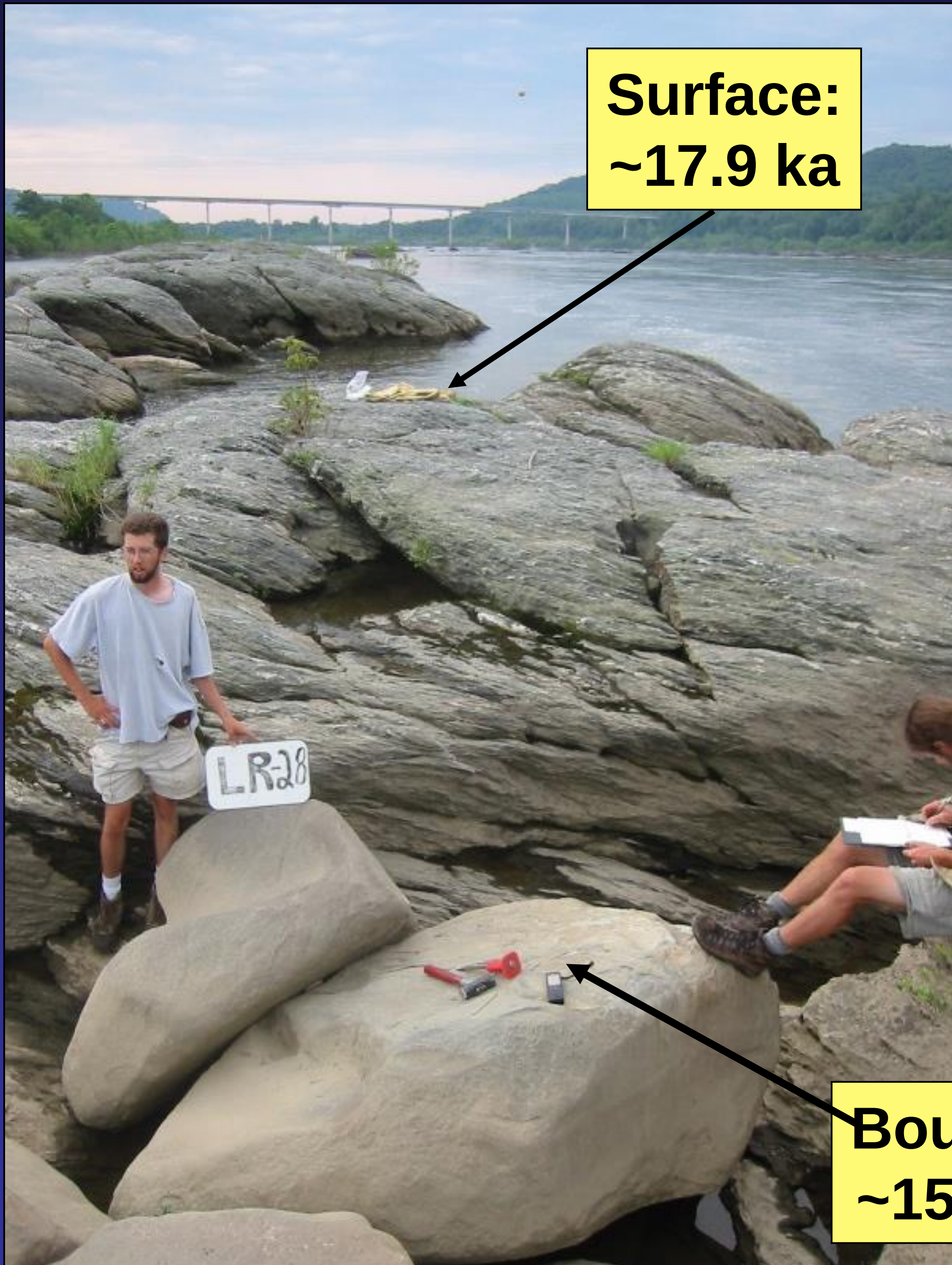

- Late Pleistocene origin
- Ages may incorporate prior Periods of burial and exposure
- Two boulders alone don’t tell us much.
- Flood origin??

Title